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Socio-Economic and Institutional Factors in Irrigation Return Flow Quality Control. Volume IV. Grand Valley Case Study

Colorado State Univ., Fort Collins

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Robert S. Kerr Environmental Research Lab., Ada, OK

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Volume IV
Grand Valley Case Study

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Volume IV: Grand Valley Case Study

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: a) investigate the nature, transport, fate, and management of pollutants in ground water; b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; c) develop and demonstrate pollution control technologies for irrigation return flows; d) develop and demonstrate pollution control technologies for animal production wastes; e) develop and demonstrate technologies to prevent, control, or abate pollution from the petroleum refining and petrochemical industries; and f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C Galegar

William C. Galegar
Director
Robert S. Kerr Environmental
Research Laboratory

PREFACE

This report concentrates on the presentation of a process for implementing technical and institutional solutions to the problem of return flow pollution. This process, under the general title of "Socio-Economic and Institutional Factors in Irrigation Return Flow Quality Control," was centered around a methodological and pragmatic definition of the problem and identification and assessment of a wide range of potential solutions for diverse situations. Four separate, but interrelated, volumes summarize the study:

Volume I -- Methodology (Main Report)
Volume II -- Yakima Valley Case Study
Volume III -- Middle Rio Grande Valley Case Study
Volume IV -- Grand Valley Case Study.

Volume I (the main report) summarizes the overall research approach of the study; the methodological premises; the nature of the problem; the process for identifying and assessing appropriate solutions; and, some general remarks and conclusions concerning the process of implementation. Volumes II to IV allow for an in-depth presentation of the approach utilized as well as specific findings and recommendations relating to the problems of each case.

The interdisciplinary team has also prepared a separate "executive summary" which is quite a shortened version and with the help of accompanying illustrations attempts to provide in a succinct form the major findings of the study as well as the propositions involved in the identification, assessment and evaluation of potential solutions concerning irrigation return flow.

ABSTRACT

The Grand Valley was used as a case study area for developing an effective process for implementing technical and institutional solutions to the problem of pollution from irrigation return flows. This area is the most significant agricultural salt source in the Upper Colorado River Basin. The primary source of salinity is from the extremely saline aquifers overlying the marine deposited Mancos Shale formation. Subsurface irrigation return flows resulting from conveyance seepage losses and overirrigation of croplands dissolve salts from this formation before returning to the Colorado River. The most cost-effective technologies for reducing the salt load are a combination of lateral lining and on-farm improvements. Farmer participation in such a program is very important. Implementation will result in excess water being available for selling, renting, or leasing to water users upstream from Grand Valley.

This report was submitted in fulfillment of Grant No. R-803572 by Colorado State University under the sponsorship of the U.S. Enviornmental Protection Agency. This report covers the period between February 14, 1975, to November 14, 1977, and work was completed as of May 4, 1978.

CONTENTS

Foreword . . . iii
Preface . . . iv
Abstract . . . v
Figures . . . viii
Tables . . . ix
Acknowledgments . . . x

1. Introduction . . . 1
    Description of the Area . . . 1
    Development of Irrigation . . . 3
    The Water Quality Problem . . . 4
    Organization of the Report . . . 7
2. Conclusions . . . 10
3. Recommendations . . . 12
4. Characteristics of the Study Area . . . 13
    Physical Characteristics . . . 13
    Economic Characteristics . . . 22
    Social Characteristics . . . 26
    Legal Characteristics . . . 32
    Summary . . . 60
5. Nature of the Problem . . . 61
    Water Quality Standards . . . 61
    Existing Water Quality . . . 62
    Sources of Water Quality Degradation . . . 69
    Future Water Quality Considerations . . . 70
6. Causes of the Problem . . . 72
    Physical Causes . . . 72
    Economic Causes . . . 73
    Legal Causes . . . 78
    Social Causes . . . 79
7. Identification of Potential Solutions . . . 81
    Physical Solutions . . . 81
    Economic Solutions . . . 83
    Legal Solutions . . . 85
    Social Solutions . . . 86
    Combinations of Solutions . . . 87
8. Assessment of Potential Solutions . . . 89
    Evaluation by Research Team . . . 89
    Field Assessment of Potential Solutions . . . 123
    Summary of Results . . . 127
References . . . 129
Appendix A . . . 133
Appendix B . . . 139

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FIGURES

Number		Page
1	The Grand Valley, Colorado	2
2	The Colorado River Basin	5
3	Relative magnitude of salt sources in the Colorado River Basin	6
4	Relative magnitude of agricultural salt sources in the Colorado River Basin.	8
5	General geologic cross-section of the Grand Valley	14
6	Conceptualized cross-section of the demonstration area geologic profile.	16
7	Normal precipitation and temperature at Grand Junction, Colorado	19
8	Grand Valley canal distribution system	21
9	Organizational representation of salinity program in Grand Valley.	30
10	Application of adjudication Procedures for Water Rights in Colorado	37
11	Agricultural land use in the Grand Valley.	64
12	Present irrigation/pollution relation.	74
13	Irrigation/pollution relation with rental market	76
14	Costs of production of agricultural crops, with and without internalization of pollution costs	77
15	Optimal on-farm water management strategies in the Grand Valley.	98
16	Minimum cost canal and ditch lining strategy for the Grand Valley	100
17	Minimum cost salinity control strategy in the Grand Valley	101

TABLES

Number Page

1 Land Use in Demonstration Area During 1969. 17

2 Value of Crops' Production, Mesa County, 1973 22

3 Uses of Land in Grand Valley, Colorado, 1973. 24

4 Use of Irrigated Land for Crops, Grand Valley, Colorado, 1969 and 1973 25

5 Crop Production Costs and Returns, Grand Valley, Colorado, 1973. 27

6 Agricultural Land Use in the Grand Valley 65

7 Grand Valley Water Budget for 1968 Water Year 66

8 Grand Valley Distribution of Canal Flows in 1968. 67

9 Salt Budget for Grand Valley During 1968. 68

10 Community Income Reduction Under Two Options for Retiring Irrigated Land in the Grand Valley Trade Area. 105

11 Summary of Annual Regional Costs and Cost Effectiveness: Upper and Lower Bound Estimates for the the Two Land Retirement Options 107

12 Summary Data Table for Taxing Alternatives. 109

13 Summary of Salinity Tax Distribution Percentages for Various Taxing Alternatives 112

14 Summary of Technological and Institutional Alternatives for Salinity Control in Grand Valley 125

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The authors are deeply indebted to the many farmers, state water resource agency personnel, and many in their capacity as managers and directors of irrigation districts and companies in the various states, who provided invaluable information to the team members during interviews and in supplying reports and data.

SECTION 1

INTRODUCTION

The general goal of this research project has been the development of an effective process for implementing technical and institutional solutions to the problem of irrigation return flow pollution. This report, based on a case study analysis of the Grand Valley in western Colorado, contains specific findings utilizing the proposed process, namely: a) definition of the problem in its physical, legal, economic, and social parameters; b) identification of potential solutions in relation to key elements of the problem; c) assessment of the potential solutions for significance and acceptability; and d) specification of those solutions which hold greatest promise of efficiency and implementability.

The approach and emphasis of the overall project, and of case studies as well, has been the specification of a process by which appropriate solutions to return flow problems are identified, evaluated and recommended for adoption. This has involved determination of technical and institutional solutions relevant to the return flow problems, but the solutions have not been the principle purpose of the research effort. This particular case study has the benefit of many years of field research by Colorado State University (CSU), which has been funded by the Environmental Protection Agency (EPA). In addition, other state and Federal agencies have been conducting research on the saline irrigation return flows from Grand Valley, all of which provides valuable insight regarding appropriate solutions.

It should be pointed out that each case study, although autonomous, should be related to the main report so that specific findings can be interpreted in the context of the more general principles and concepts which are involved in the process of implementation.

DESCRIPTION OF THE AREA

The Grand Valley is located in west central Colorado at the confluence of the Gunnison and Colorado Rivers in Mesa County (Figure 1). Paralleling the Colorado River for about 30 miles (48.3 km), the Valley averages seven miles (11.3 km) in width and about 4,400 feet (1,340 meters) in elevation. Summer weather is characteristically hot and dry and the winters cold. Beginning in April, the normal frost-free season averages about 190 days. With annual precipitation averaging slightly more than 8 inches (200 mm), irrigation is necessary to maintain a viable commercial agriculture in the Valley.

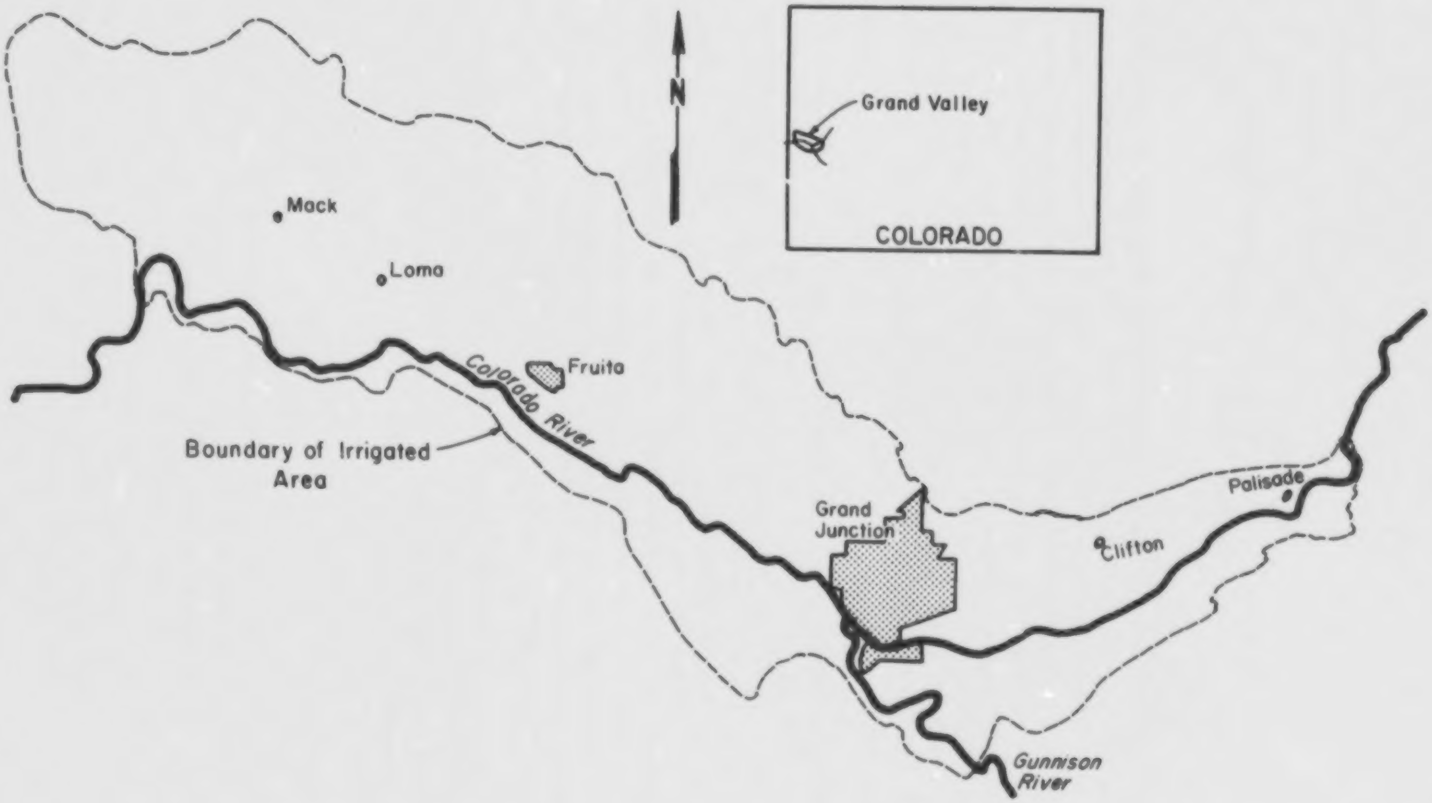

Grand Valley
COLORADO
N
Mack
Loma
Fruita
Colorado River
Boundary of Irrigated Area
Grand Junction
Clifton
Palisade
Gunnison River

Figure 1. The Grand Valley, Colorado.

Grand Junction, with a population of about 25,000, is the principal commercial center in the Valley, and in Colorado's western slope. Agriculture is an important source of employment and income to a local population of nearly 60,000 people in Mesa County. However, in recent years basic manufacturing and service industries have become the mainstay for an otherwise traditional agricultural community (Leathers and Young, 1976). Approximately 56,000 acres (22,680 hectares) of land are presently cultivated out of a total area exceeding 100,000 acres (40,500 hectares). Urban and industrial expansion, service roads and farmsteads, and idle and abandoned lands account for most of the balance not farmed (Walker and Skogerboe, 1971).

The diversified agricultural industry in the Valley is comprised of both livestock and crop production activities. Major crops grown include corn, alfalfa, sugar beets, small grains, and permanent pasture. Slightly less than ten percent of the irrigated acreage is planted to pome and deciduous orchards. Small acreages of vegetables and other specialty crops such as turf grass are also grown in the area. The Grand Valley has long been favored wintering area for cattle and sheep grazed on high summer ranges to the east and south (Leathers and Young, 1976).

DEVELOPMENT OF IRRIGATION

Although numerous hieroglyphics and abandoned ruins testify to occupation of the Colorado River Basin long before settlement began, the first people encountered in the Grand Valley were the Ute Indians. The first contact these people had with white men was recorded in 1776 when an expedition led by Fathers Dominquez and Escalante passed north of what was later to be Grand Junction and across the Grand Mesa (Hafen, 1927). The region was subsequently visited by fur trappers, traders and explorers. In 1839, one such trader named Joseph Roudeau built a trading post just upstream from the present site of Grand Junction.

In 1853, Captain John W. Gunnison led an exploration party into the Grand Valley from up the Gunnison River Valley in search of a feasible transcontinental railroad route (Beckwith, 1854). As Captain Gunnison and his party traversed the confluence of the Colorado and Gunnison Rivers, an error was made by the expedition recorder as to the proper naming of the river. Beckwith referred to the Gunnison River as the Grand River and the Colorado River as the Blue River, or "nah-un-Kah-rea," as it was known to the Indians. The mistake was later corrected, however, since the Colorado River was known as the Grand River as early as 1842 (Fremont, 1845). Field surveys conducted by Hayden (Hayden, 1877) in 1875 and 1876 found only the Ute Indians in the Valley, and skirmishes with some of the hostile Utes cut short the 1875 expedition. As a result of the Meeker Massacre of 1879, the Utes were forced to accept a treaty moving them out of Colorado and onto reservations in eastern Utah. After the completion of the Utes' exit in September 1881, the Valley was immediately opened up for settlement for the first ranch staked out on September 7, 1881, near Roudeaus' trading post. Later that year, on September 26, George A. Crawford founded Grand Junction as a townsite and formed the Grand Junction Town Company, October 10, 1881. On November 21, 1882, the Denver and Rio Grande Railroad narrow-gauge line was completed to

Grand Junction via the Gunnison River Valley and thus assured the success of the settlement.

Following settlement in the early 1880's, irrigation companies were organized to divert water for agricultural use. Many of the original companies have been consolidated, leaving five which presently supply all the water diverted under original decrees: the Grand Valley Irrigation Company (1882); the Grand Valley Water Users Association, using water developed by the U.S. Bureau of Reclamation in 1916; the Palisade and Mesa County Irrigation Districts (1890's); and the Redlands Water and Power Company (Skogerboe and Walker, 1972). Because irrigable acreages were typically overestimated within the newly-formed irrigation districts, and due partially to a gradual decline in irrigated acreage as a result of waterlogging and more recently urbanization, Grand Valley farmers have always had an abundant supply of water.

THE WATER QUALITY PROBLEM

Salinity is the most pressing problem facing the future development of water resources in the Colorado River Basin (Figure 2). Because of the progressive deterioration in mineral quality towards the lower reaches, the detrimental effects of using an increasingly degraded water are first seen in the Lower Basin. As a result of the continual development in the Upper Basin, most of which will be diversion out of the Basin to meet large municipal and industrial needs, water ordinarily available to dilute the salt flows will be depleted from the system, causing significant increases in salinity concentrations throughout the Basin. The economic penalty resulting from a use of lower quality water will be incurred by those users in the lower system. The U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1971) has estimated that present economic losses from salinity, due to loss of agricultural productivity and added costs of water treatment and conditioning in urban areas, are $16 million annually. If water resources development proceeds as proposed without implementing a salinity control program, the average annual economic detriments (1970 dollars) would increase to $28 million in 1980 and $51 million in 2010 (U.S. Environmental Protection Agency, 1971). These damages do not reflect costs to Mexico.

A more detailed examination of the basinwide problems is summarized in Figure 3, which clearly demonstrates the necessity of attacking salinity basinwide. As indicated, the bulk of the salt loads passing into the lower reaches is attributable to the Upper Basin. Salinity management in the Upper Basin must, therefore, concern itself with the aspect of salt loading in the river system from municipal, industrial, agricultural, and natural sources. The other aspect, which is the salt concentrating effects, is related to consumptive use, evaporation and transbasin diversions. Although several methods of controlling salinity--such as phreatophyte eradication (although controversial from a wildlife standpoint) and evaporation suppression on reservoirs--are desirable, the most feasible solutions are in reducing inflows from mineralized springs and more efficient irrigation practices. In any case, the salinity management objectives in the Upper Basin must necessarily be concerned with a reduction in the total salt load being carried to

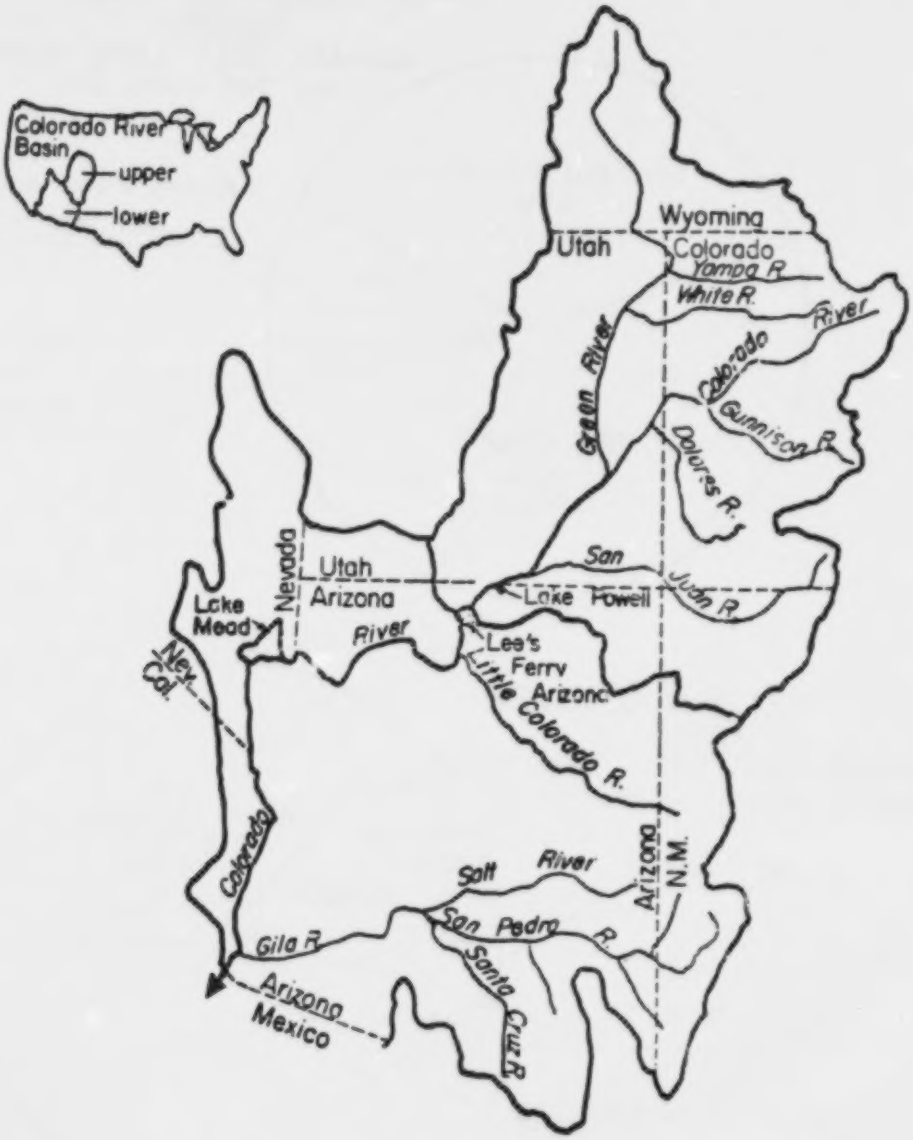

Colorado River Basin
upper
lower
Wyoming
Utah
Colorado
Yampa R.
White R.
River
Green River
Colorado
Gunnison R.
Dolores R.
San
Juan R.
Nevada
Utah
Arizona
Lake Powell
Lake Mead
River
Lee's Ferry
Arizona
Little Colorado R.
Nev.
Cal.
Colorado
Salt River
Arizona
N.M.
San Pedro R.
Santa Cruz R.
Gila R.
Arizona
Mexico

Figure 2. The Colorado River Basin.

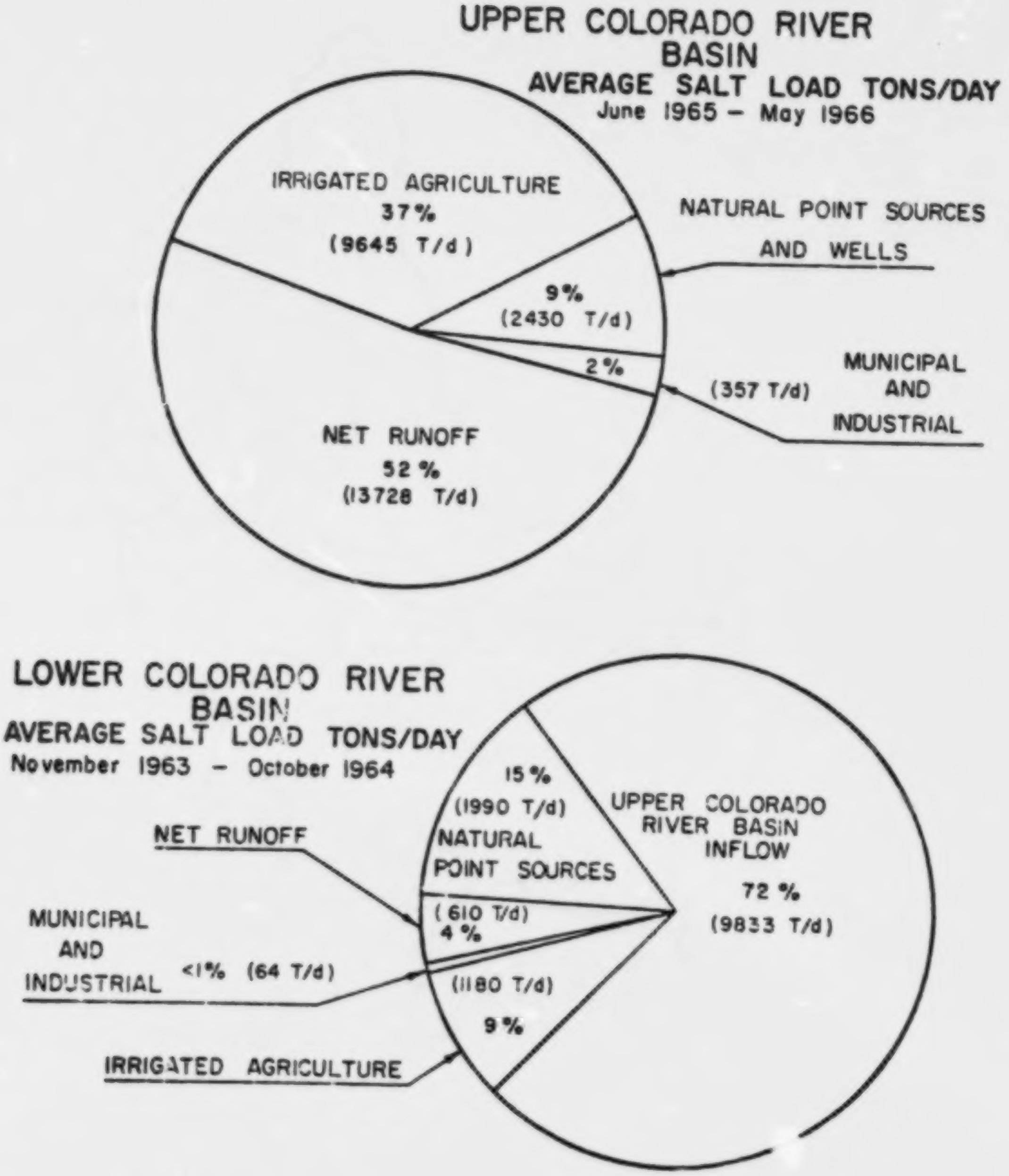


Figure 3. Relative magnitude of salt sources in the Colorado River Basin (from U.S. Environmental Protection Agency, 1971).

the Lower Basin in order that the detrimental salinity effects anticipated from further development can be limited. Salinity control must be practiced at all locations in the Basin if the economic losses to downstream users are to be minimized.

Since the Colorado River Basin is not a rapidly growing municipal and industrial area, the population problems are primarily associated with agriculture, as illustrated in Figure 3. Thus, the major aspect of reducing the salt inputs in the Upper Basin must be the effective utilization of the water presently diverted for irrigation by comprehensive programs of conveyance channel lining, increasing irrigation efficiency on the farms, improved irrigation company management practices, and more effective coordination of problem areas. Salinity is no longer a local problem and should be considered regionally.

In irrigated areas, it is necessary to maintain an acceptable salt balance in the crop root zone which requires some water for leaching. However, when irrigation efficiency is low and conveyance seepage losses are high, the additional deep percolation losses are subject to the highly saline aquifers and soils common in the basin and result in large quantities of salt being picked up and carried back to the river system. Therefore, a need exists to delineate the high input areas and examine the management alternatives available to establish the most effective salinity control program.

Probably the most significant salt source in the Upper Basin is the Grand Valley area (Figure 1) in west central Colorado. The Colorado River enters the Grand Valley from the east, is joined by the Gunnison River at Grand Junction, Colorado, and then exits to the west. The contribution to the total salt flows in the Basin from this area, illustrated in Figure 4, is highly significant. The primary source of salinity is from the extremely saline aquifers overlying the marine deposited Mancos shale formation. The shale is characterized by lenses of salt in the formation which are dissolved by water from excessive irrigation and conveyance seepage losses when it comes in contact with the Mancos shale formation. The introduction of water through these surface sources percolates into the shallow ground water reservoir, where the hydraulic gradients it produces displace some water into the river. This displaced water has usually had sufficient time to reach chemical equilibrium with the salt concentrations of the soils and shale. These factors also make the Grand Valley an important study area, since the conditions encountered in the Valley are common to many locations in the Basin.

ORGANIZATION OF THE REPORT

The purpose of this report is to identify the specific causes of the water quality problems in the study area, to identify alternative solutions to these problems, to analyze these alternatives, and finally, to suggest the means for implementing solutions to the problems.

In order to insure the most complete discussion possible for the various aspects affecting the water quality situation in the Grand Valley, the

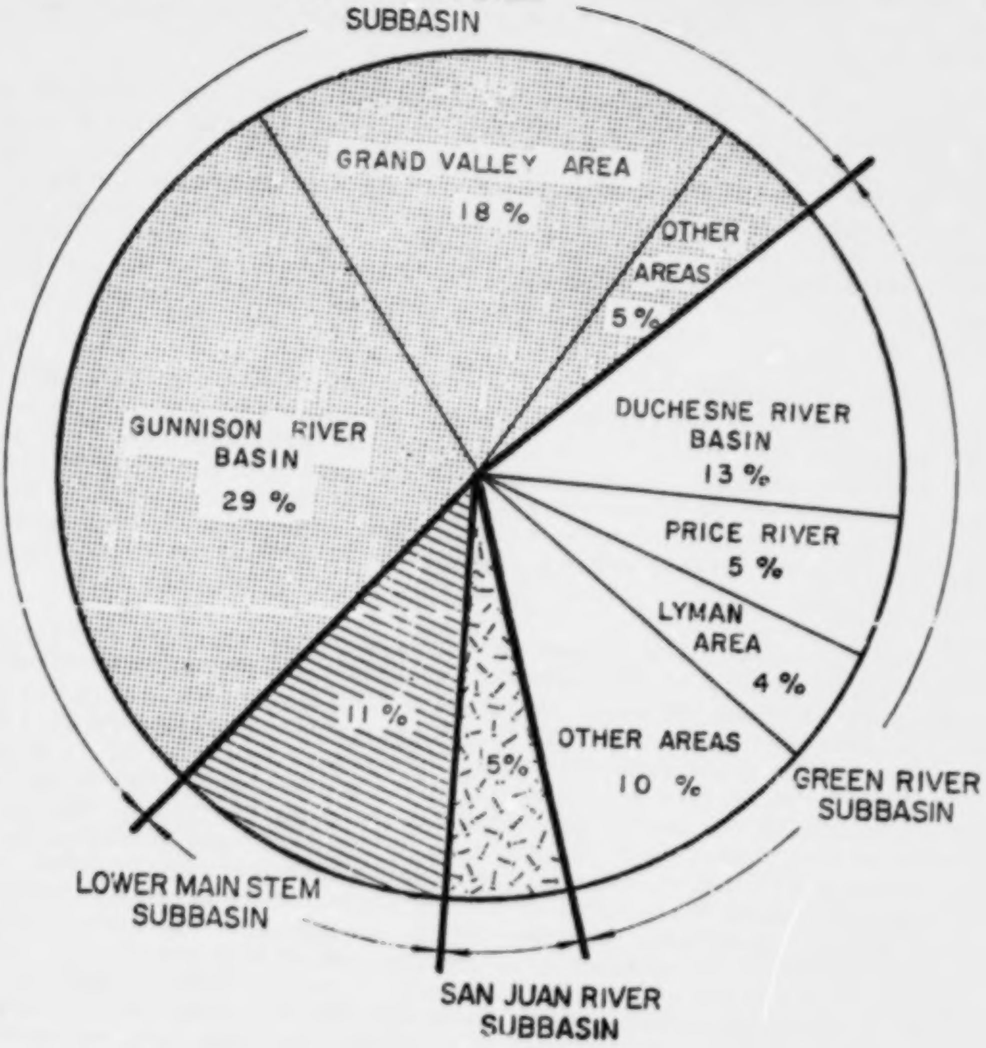


Figure 4. Relative magnitude of agricultural salt sources in the Colorado River Basin (from U.S. Environmental Protection Agency, 1971).

characteristics of the study area, causes of the water quality problems and identification of potential solutions are described according to their physical, economic, legal, and social dimensions.

SECTION 2

CONCLUSIONS

The salt load contribution from Grand Valley is largely the result of saline subsurface irrigation return flows reaching the Colorado River. The alluvial soils of Grand Valley are high in natural salts; however, the most significant salt source is the Mancos shale formation underlying these alluvial soils which contain crystalline lenses of salt that are readily dissolved by the subsurface return flows.

Added to this geologic setting is an irrigation water supply which averages at least three times greater than the crop water requirements. Although much of this excess water returns to open drains as surface runoff, which has negligible impact upon the salinity in the Colorado River, there are still significant quantities of water that reach the underlying Mancos shale formation. These subsurface return flows are the result of seepage losses from canals and laterals, and excessive deep percolation losses from overirrigation of the croplands.

The excessive irrigation water supplies are the result of early development in 1882 of irrigation systems in Grand Valley, which results in the Grand Valley Irrigation Company having the first right (i.e., earliest priority) to water on the Colorado River in the state of Colorado. The various irrigation companies in Grand Valley have many early water rights. During extreme drought years, only the Government Highline Canal has to reduce its diversions.

The irrigation companies generally terminate their responsibility to the irrigators at the turnout gates along the canals which discharge water into the laterals. Generally, the water users under each lateral are only informally organized. Also, they lack flow measuring devices which greatly hinders their ability to equitably distribute the waters. Thus, the combination of geologic setting, early water rights that yield abundant irrigation water supplies, lack of responsibility of irrigation companies to individual waters users, the almost complete absence of flow measuring devices along the laterals, and the low annual charges for irrigation water all contribute to the salinity problem.

The most cost-effective technologies for reducing the salt load from Grand Valley are a combination of lateral lining and on-farm improvements. Farmer participation in such a program is very important. The construction of physical facilities and the development of improved irrigation practices requires considerable technical assistance in organizing the farmers under each lateral into a water users association and to insure that improved water management practices are adopted by the farmers in order to realize the potential of the constructed physical facilities.

The retirement of some croplands which are relatively unproductive should be considered, since a salinity control program will lower presently existing high water tables, waterlogged soils will be drained, and some of the now unproductive cropland--which deteriorated decades ago because of poor water management--may be returned to a much higher level of productivity. The implementation of such a program will result in excess water being available for rent or sale to water users upstream from Grand Valley. Sale of portions of annual allotments will cause prices of water to rise beyond diversion and distribution costs and will encourage more efficient use of water in agricultural production. When applications of water to crops are reduced to levels which approximate requirements for growth, return flows will be diminished and the salinity problem reduced.

SECTION 3

RECOMMENDATIONS

A salinity control program should be implemented which involves a combination of lateral lining and on-farm improvements. This program should be implemented on a lateral-by-lateral basis, where those personnel providing technical assistance would meet with all of the water users under any particular lateral to develop a plan of improvement. In addition, technical assistance personnel would assist the water users in becoming formally organized in order to implement the plan and provide improved operation, maintenance and management following construction.

The State Engineer's Office should develop standards and criteria for beneficial use of irrigation water in Grand Valley. This will encourage or require limitation of applications of water to approximate the consumptive use by crops. Deep percolation of excess water and saline return flows would be correspondingly reduced.

To assist in local water management, farmers on the laterals should organize into mini-companies to improve the delivery efficiencies and undertake more than mere distribution of water as it is delivered to them.

State legislation is needed that would authorize the irrigation companies in Grand Valley to rent or sell the excess water resulting from this salinity control program to water users upstream from Grand Valley. The revenues from such water transfers could be used to line the canals or to implement other water management technologies.

SECTION 4

CHARACTERISTICS OF THE STUDY AREA

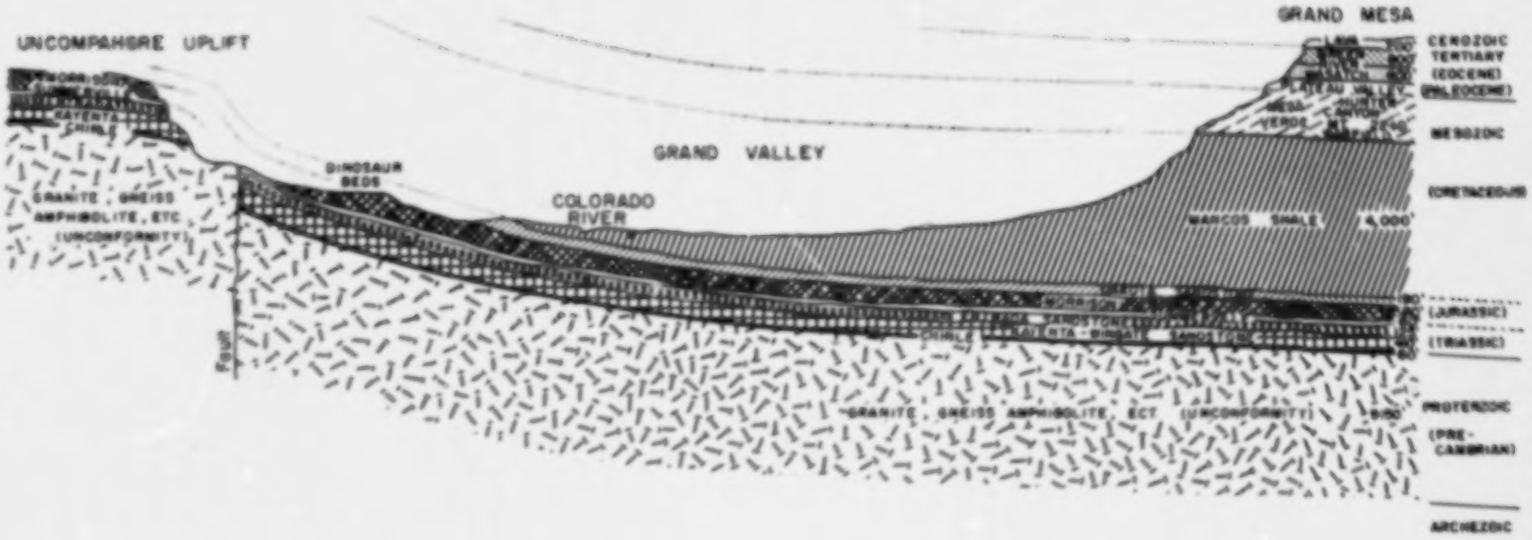
PHYSICAL CHARACTERISTICS

Geology

The plateaus and mountains in the Colorado River Basin are the product of a series of uplifted land masses deeply eroded by wind and water. However, long before the earth movements which created the uplifted land masses, the region was the scene of alternate encroachment and retreat of great inland seas. The sedimentary rock formations underlying large portions of the Basin are the result of material accumulated at the bottom of these seas. In areas similar to the Grand Valley, the upper portions contain a large number of intertonguing and overlapping formations of continental sandstone and marine shales, as shown in Figure 5. The lower parts are mostly marine Mancos shale and the Mesa Verde group of related formations. This particular geology is exhibited in about 23 percent of the Basin in such common locations as the Book Cliffs, Wasatch, Aquarias, and Kaiparowitz Plateaus, the cliffs around Black Mesa, and large areas in the San Juan and Rocky Mountains.

The geology of an area has a profound influence on the occurrence, behavior and chemical quality of the water resources. In the mountainous origins of most water supplies, a continuous interaction of surface water and ground water occurs when precipitation in the form of rain and melting snow enters ground water reservoirs. Eventually, these quantities of ground water return to the surface flows through springs, seeps, and adjacent soil in regions downstream. A further consequence of such a flow system is the addition of water from streams to the ground water storage during periods of high flows and subsequent return flows during low flow periods. The resulting continuous interaction of surface water and ground water allows contact with rocks and soils of the region which affect the chemical characteristics imparted to the water.

The interior valleys of the Basin (the Grand Valley is a good example) do not receive large enough amounts of precipitation to significantly recharge the ground water storage. Usually, the water bearing aquifers are buried deep below the Valley floor and are fed in and along the high precipitation areas of the mountains. Shallow ground water supplies are predominantly the result of irrigation. Although the water in the consolidated rock formations of the Valley region does not contribute significantly to the stream flows as is the case in higher elevations, it does have a pronounced effect on water quality due to the large volumes of natural salts contained in these formations.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GRAND MESA
MESA VERDE
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MESOZOIC
(CRETACEOUS)
(JURASSIC)
(TRIASSIC)
PROTEROZOIC
(PRE-CAMBRIAN)
ARCHEZOIC

Figure 5. General geologic cross-section of the Grand Valley (from U.S. Department of Agriculture, Soil Conservation Service, 1955; Soil Surveys, Grand Junction Area, Colorado).

High intensity thunderstorms bring surface runoff in contact with the rocks and soils which then distribute their chemical characteristics. Erosion by rivers and streams has deposited alluvium high in natural salts along certain valleys, with these natural salts being returned to the surface waters when moisture, from either precipitation or irrigation, percolates through the alluvial soils.

Soils

The desert climate of the area has restricted the growth of natural vegetation, thereby causing the soils to be very low in nitrogen content because of the absence of organic matter. The natural inorganic content is high in calcite, gypsum and sodium, patassium, magnesium, and calcium salts. With the addition of irrigation, some locations have experienced high salt concentrations with a resulting decrease in crop productivity. Although natural phosphate exists in the soils, it becomes available too slowly for use by cultivated crops and a fertilizer application greatly aids yields. Other minor elements such as iron are available except in those areas where drainage is inadequate. The soils are of relatively recent origin as they contain no definite concentration of lime or clay in the subsoil as could be expected in weathered soils. The soils in the area were classified by the Soil Conservation Service in cooperation with the Colorado Agricultural Experiment Station in 1940 (U.S. Department of Agriculture, Soil Conservation Service, and Colorado Agricultural Experiment Station, 1955, Soil Surveys, Grand Junction Area, Colorado, Series 1940, No. 19, November). Some areas in the Valley have limited farming use because of poor internal drainage, which results in waterlogging and salt accumulations.

Lying on top of the Mancos shale and below the alluvial soils is a large cobble aquifer extending north from the river to about midway up the test area, as illustrated in Figure 6. The importance of this aquifer with respect to the drainage problems of the area has been demonstrated by a cooperative study in 1951 between the Colorado Experiment Station in conjunction with the Agricultural Research Service (ARS) (U.S. Department of Agriculture and Colorado Agricultural Experiment Station, 1957), which evaluated the feasibility of pump drainage from the aquifer.

Land Use

Evaporation and transpiration from crops, phreatophytes and other land use results in a loss of salt-free water to the atmosphere and deposition of salt in the soil profile. The magnitude of these losses depends on the acreage (hectares) of each water use. As a part of a valleywide evaluation, the various acreages of land uses were mapped. The acreages for each land use are shown in Table 1 (Walker and Skogerboe, 1971). One of the most quoted statements in the literature concerning the Grand Valley is that approximately 30 percent of the farmable area is unproductive because of the ineffectiveness of the drainage in these areas. Examination of the results presented in Table 1 indicates that 70 percent of the study area can be classified as irrigable land; however, only 52 percent can be considered productive. The use of the term productive relates to the areas producing cash crops such as corn, beets, grains, orchards, alfalfa, etc. The land use summary for the entire Valley will be presented in a later section.

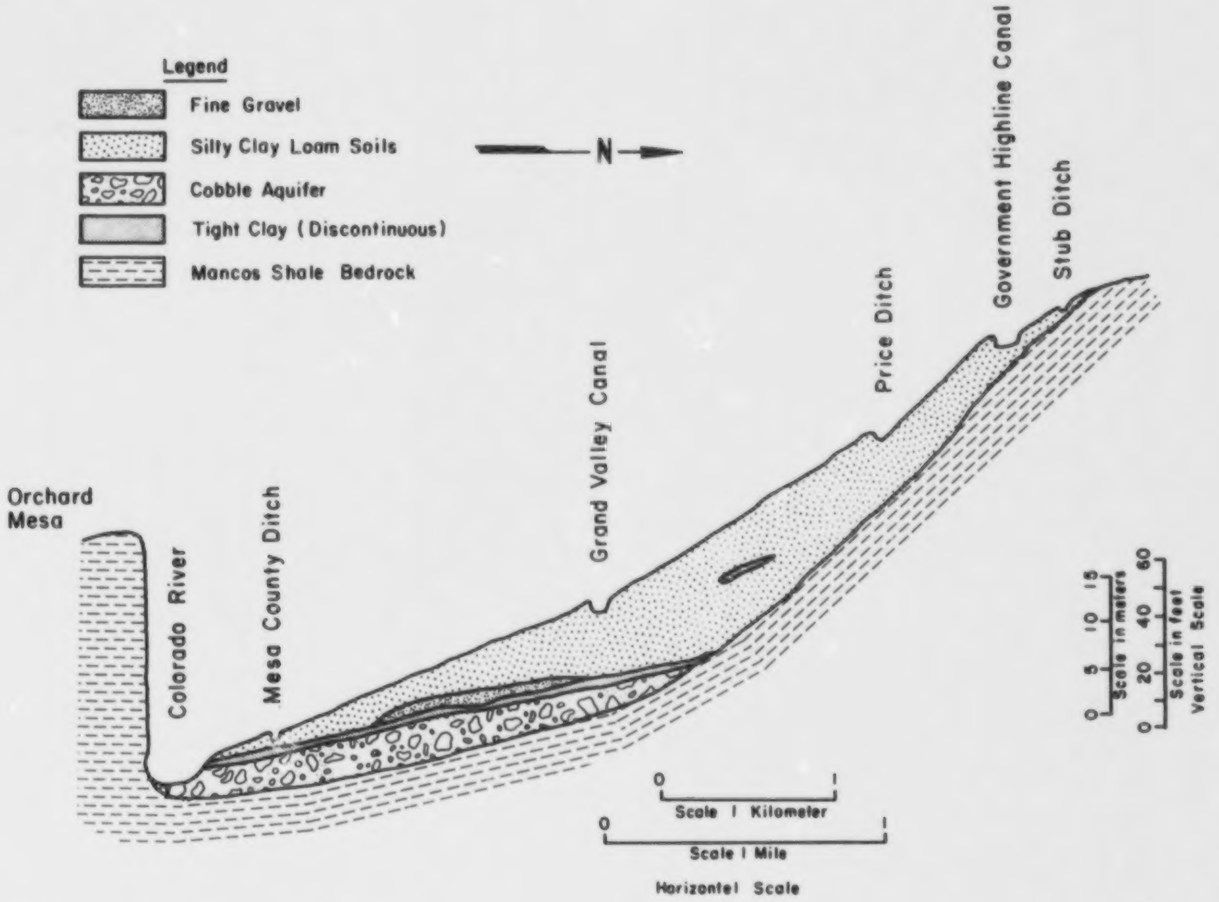
Legend
Fine Gravel
Silty Clay Loam Soils
Cobble Aquifer
Tight Clay (Discontinuous)
Mancos Shale Bedrock
N
Orchard Mesa
Colorado River
Mesa County Ditch
Grand Valley Canal
Price Ditch
Government Highline Canal
Stub Ditch
0
Scale 1 Kilometer
0
Scale 1 Mile
Horizontal Scale
0 5 10 15
Scale in meters
0 20 40 60
Scale in feet
Vertical Scale

Figure 6. Conceptualized cross-section of the demonstration area geologic profile.

TABLE 1. LAND USE IN DEMONSTRATION AREA DURING 1969 (Walker and Skogerboe, 1971).

Classification	Acreage	Hectares	Total Ac.	Total Ha.	Percent
A1 Corn	487	197.00			
A2 Sugar beets	1	0.41			
A3 Potatoes	8	3.24			
A7 Barley	255	103.28			
A8 Oats	14	5.67			
A9 Wheat	9	3.65			
A10 Alfalfa	545	220.73			
A12 Cultivated grass and hay	141	57.11			
A13 Pasture	476	192.78			
A15 Native grass pasture	387	156.74			
A16 Orchard	349	141.35			
A17 Idle	559	226.40			
A18 Other	6	2.43			
SUBTOTAL			3237	1310.99	69.9
C1 Farmsteads	258	104.49			
C2 Residential yards	61	24.71			
C3 Urban	85	34.43			
C4 Stockyards	8	3.24			
SUBTOTAL			412	166.86	8.9
E4 Open water surfaces	70	28.35			
SUBTOTAL			70	28.35	1.5
F1L Cottonwood (light)	3	1.22			
F1H Cottonwood (heavy)	3	1.22			
F2M Salt Cedar (medium)	15	6.08			
F2H Salt Cedar (heavy)	253	102.47			
F3L Willows (light)	7	2.84			
F3H Willows (heavy)	63	25.52			
F4L Rushes (light)	1	0.41			
F4H Rushes (heavy)	9	3.65			
F5L Greasewood (light)	67	27.14			
F5M Greasewood (medium)	104	42.12			
F5H Greasewood (heavy)	162	65.61			
SUBTOTAL			687	278.24	14.8
Precipitation only	255	91.13			
SUBTOTAL			225	91.13	4.9
			4631	1875.56	100.0

Climate

The mountain ranges in the Upper Colorado River Basin have much more influence on the climate than does the latitude. The movement of air masses is disturbed by the mountain ranges to the extent that the high elevations are wet and cool, whereas the low plateaus and valleys are drier and subject to wide temperature ranges. A common characteristic of the climate in the lower altitudes is hot and dry summers and cold winters. Moist Pacific air masses can move across the Basin, but dry polar air and moist tropical air rarely continue all the way across the Basin. Movement of both types of air mass is obstructed and deflected by the mountains so that their effects within the Basin are weaker and more erratic than in most areas of the country.

Most of the precipitation to the Basin is provided from the Pacific Ocean and the Gulf of Mexico whose shores are 600 (965.40 km) and 1,000 miles (1,609 km) from the center of the Basin, respectively. The air masses are forced to high altitudes and lose much of their precipitation before entering the Basin. During the period from October to April, Pacific moisture is predominant, but the late spring and summer months receive moisture from the Gulf of Mexico.

The monthly distribution of precipitation and temperature for Grand Junction is shown in Figure 7 (U.S. Department of Commerce, 1968). The climate in the area is marked by a wide seasonal range, but sudden or severe weather changes are infrequent due mainly to the high ring of mountains around the Valley. This protective topography results in a relatively low annual precipitation of approximately eight inches. The usual occurrence of precipitation during the growing season is in the form of light showers from thunderstorms which develop over the western mountains. The nature of the Valley location with typical valley breezes provides some spring and fall frost protection resulting in an average growing season of 190 days from April to October. Although temperatures have ranged to as high as 105°F (41°c), the usual summer temperatures range in the middle and low 90's (low 30'sc) in the daytime to the low 60's (16°-21°c) at night. Relative humidity is usually low during the growing season, which is common in all of the semi-arid Colorado River Basin.

Irrigation

The system of irrigation most common to the area is surface flooding either by borders or furrows. The study area itself is located in the narrow eastern part of the Valley which has a relief of about 50 feet per mile (8.25 m/km) sloping south towards the river. As a result, care is taken to prevent erosion in most cases by irrigation with small streams. Most farms in the area are small and have short-run lengths, and the small irrigation stream allows adequate application. The quantity of water delivered to the farmer is plentiful so the usual practice is to allow self-regulated diversions. Although the method of irrigation is quite similar throughout Grand Valley, there is considerable contrast in land use. The lands at the upper end (eastern) of the Valley are largely orchards, which is also the case for the Orchard Mesa lands south of the Colorado River. In contrast to the demonstration area, larger tracts of farm land are located in the western portions of the Valley,

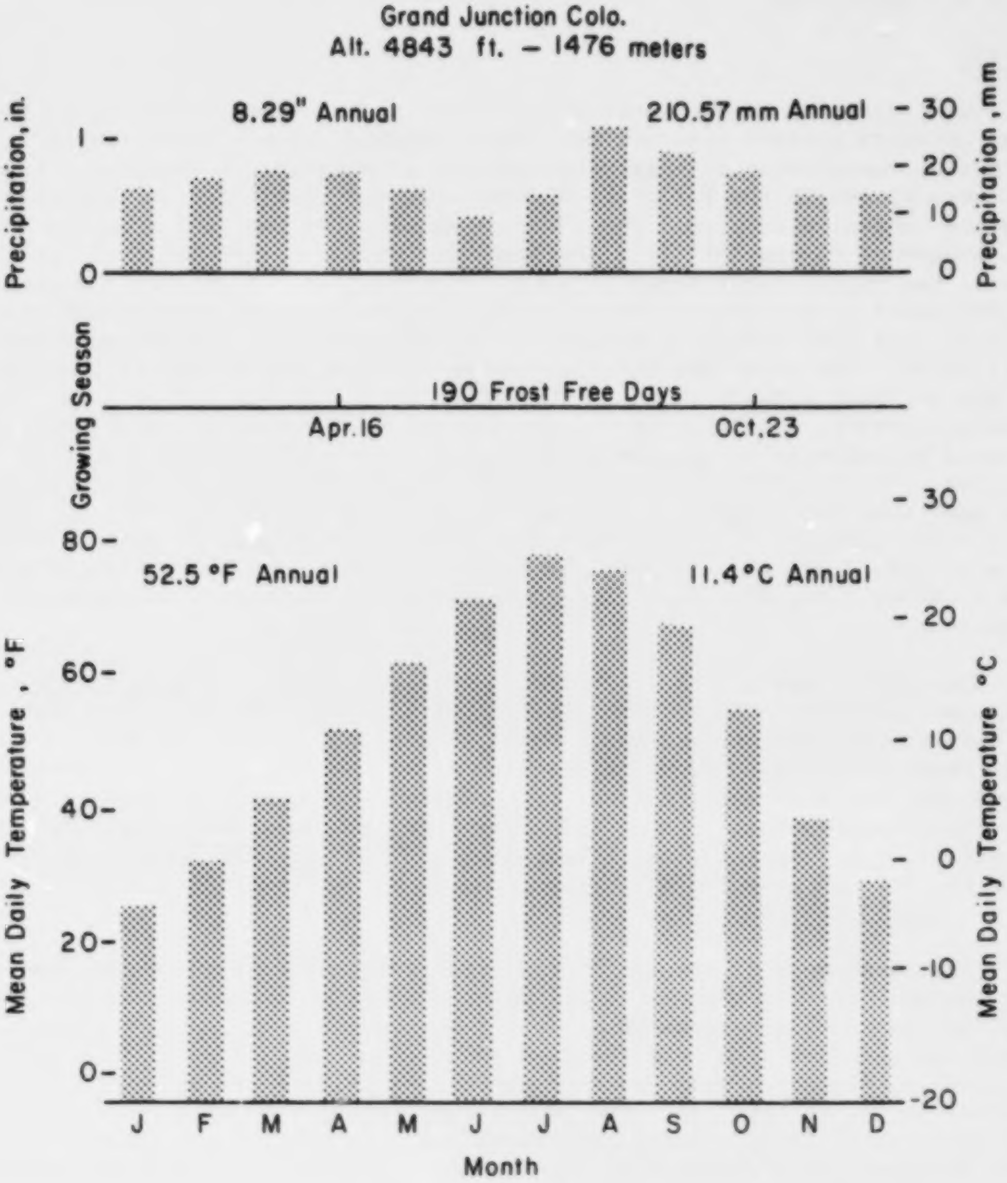

Figure 7. Normal precipitation and temperature at Grand Junction, Colorado (Skogerboe and Walker, 1972).

with many of these lands having good soils which contribute to the production of high yield crops.

Canals

Consideration of the water distribution system is an essential part of most salinity control alternatives, which suggests that a broader perspective of system improvement as a salinity control alternative is required. The delivery system in the Valley is divided into the canal or ditch subsystem and the lateral subsystem. The division between the two subsystems is based on management responsibility. The canal companies and irrigation districts divert the appropriated water directly from the river, transport the water in the canal subsystem, and control the delivery of water through the canal turnout, but they generally assume little responsibility for the water below this point. The canal and ditch subsystem can thus be defined as that part of the delivery network which is controlled by irrigation authorities. The lateral network, extending beyond the turnout from the canal or ditches, is managed by cooperative agreements between the individual users served by the turnout. The transfer of responsibility between the two entities should be the equitable measurement and charge for the water at the turnout, but there is little incentive to make this effort with the abundance of water. A notable exception are the turnouts comprising the Water Users Association under the Government Highline Canal, where individual measurements are made and recorded.

The canals and ditches in the Grand Valley, shown in Figure 8, are operated and maintained by separate irrigation organizations. Discharge capacities at the head of the canals range from above 700 cfs (20 cms) in the Government Highline Canal to 30 cfs (1 cms) in the Stub Ditch and diminish along the length of each canal or ditch. The lengths of the respective canal systems are approximately 55 miles (89 km) for the Government Highline Canal, 12 miles (19 km) each for the Price, Stub and Redlands Ditches, 110 miles (177 km) for the Grand Valley system, and 36 miles (58km) for the Orchard Mesa Canals.

The management of the canals and ditches in the area varies between canals, as well as with changes in the water supply. For example, it was noted earlier that during periods when river flows become small, restrictions are placed on the diversion into the Government Highline Canal. This is possible because the flows are measured and recorded at each individual turnout in that system, and it is required since their water rights are junior to others. On the other hand, in most instances, along the other canals measurements are not made because little shortage is experienced. Another practice used extensively in the region is the regulation of canal discharges at points in the system by varying the amounts of spillage into the natural wasteways and washes. Neither of these practices--inadequate flow measurement and canal spillage--is conducive to salinity control.

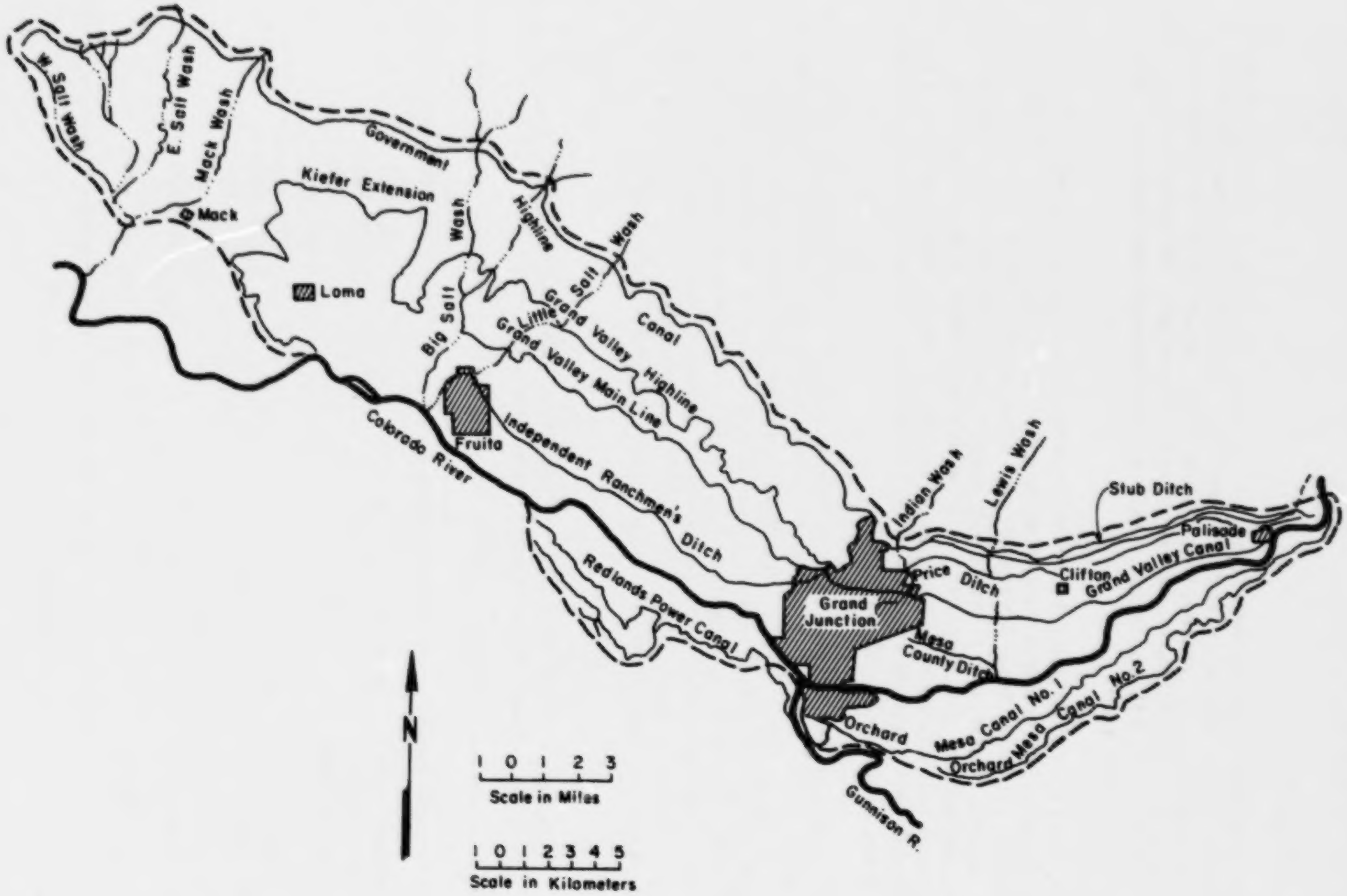
W. Salt Wash
E. Salt Wash
Mack Wash
Mack
Government
Kiefer Extension
Loma
Wash
Highline
Salt Wash
Big Salt
Canal
Little
Grand Valley Highline
Grand Valley Main Line
Fruita
Independent Ranchmen's Ditch
Colorado River
Redlands Power Canal
Indian Wash
Lewis Wash
Stub Ditch
Palisade
Clifton
Grand Valley Canal
Price Ditch
Grand Junction
Mesa County Ditch
Orchard
Mesa Canal No. 1
Orchard Mesa Canal No. 2
Gunnison R.
N
1 0 1 2 3
Scale in Miles
1 0 1 2 3 4 5
Scale in Kilometers

Figure 8. Grand Valley canal distribution system.

ECONOMIC CHARACTERISTICS

General Composition

Though the Grand Valley has long been a traditional agricultural community, in recent years manufacturing and service industries have become significant. Ninety percent of the employed work force is occupied in nonagricultural business and manufacturing enterprises. There are 18 manufacturers with 20 or more employees, 135 wholesale trade establishments and more than 600 retail stores in the area.

But agriculture continues to be an important source of income and employment to the 50 thousand people of the Valley. The diversified agricultural industry includes both livestock and crop production activities, and there are several important firms which supply feeds, seeds, fertilizers, irrigation equipment, and machinery. In addition, there are warehousing, processing and transporting industries that add value to the crops and livestock produced, making them available to wholesalers, retailers and consumers at appropriate times and places.

Major crops of the Valley include corn, alfalfa, sugar beets, small grains, and pasture. About 10 percent of the irrigated acreage is planted to pome and deciduous fruit trees. The Valley is perhaps best known for its fruits, some of which are shipped as far as the Atlantic seaboard. Only a few cattle are raised in the Valley, but it has long been a favorite wintering area for livestock grazed on pastures in adjacent mountains during the summer time. Table 2 shows the values of crops produced in Mesa County in 1973. The major portion of these crops were produced in the Valley.

TABLE 2. VALUE OF CROPS' PRODUCTION, MESA COUNTY, 1973
(U.S. Department of the Interior, 1973)

Crop	Value
All wheat	$ 290,000
Corn for grain	2,455,400
Corn for silage	940,800
Barley	301,200
Dry beans	103,000
Sugar beets	2,215,000
Oats	205,700
All hay	3,880,200
Other crops*	3,890,200
TOTAL ALL CROPS	$13,363,300

* Includes rye, fruits and vegetables.

Agricultural Production and Resource Use

A land use survey completed in 1973 found 122,000 acres (49,410 ha) of land in the area served by irrigation companies and districts. Of this, 71,000 acres (28,755 ha) were considered to be irrigable and 57,500 acres (23,288 ha) were devoted to crops which were harvested and pastured.

Walker and Skogerboe described land use in the Valley in a general way:

> The distribution of cropland in the Grand Valley seems to have been affected largely by the temperature variations within the Valley. For example, in the eastern end of the Valley (where the Valley is narrow), the crops are almost dominantly orchard. In the center of the Valley, in the proximity of Grand Junction or nearby, the land is primarily pasture and/or alfalfa. Finally, in the western end of the Valley due to the shorter growing season, deeper soils, and fairly good drainage, the land is used almost exclusively for corn, alfalfa, and sugar beets as money crops (Walker and Skogerboe, 1971).

A summary of land use is contained in Table 3. There is an account of use of all the irrigable lands, 71,405 acres (28,919 ha), and in addition there are estimates of acreages employed for urban uses, occupied by phreatophytes and maintained simply as part of the watershed.

Within the last decade, there have been some noticeable changes in the use of irrigated lands for crops, e.g., in the cropping patterns. In particular, the acreages of orchard and truck crops and sugar beets have changed, declining moderately but constantly each year. The cropping pattern for 1973 is reflected in Table 4. Also shown are crop acreages in 1969.

Role of Irrigation

Facilities for diversion of water for irrigating in the Grand Valley were first developed by irrigation companies in the late 1870's and the 1880's. There was a tendency for overestimation of acreages within the territories of the new companies. As a consequence, early reports of irrigation were inaccurate, but the optimistic estimates of irrigated acreages were the basis for water diversions, so there was (and continues to be) abundant supplies of water for developed land.

Through the years, some of the irrigation companies failed and others were consolidated, so that today there are five companies which supply all of the water diverted under original decrees. These are: The Grand Valley Irrigation Company, the Grand Valley Water Users Association, the Palisade Irrigation District, the Mesa County Irrigation District, and the Redlands Water and Power Company. Water was developed by the Bureau of Reclamation in 1916 and is distributed by the Grand Valley Water Users Association.

In the last two or three decades there has been a decline in the acreage irrigated due to waterlogging of some soils. This is indicative of problems of management of soils and water, probably of overirrigation which caused

TABLE 3. USES OF LAND IN GRAND VALLEY, COLORADO, 1973[1] (Leathers, 1975).

Classification	Colorado River Water				Private Systems		Gunnison River Water				Total	
	Govt. Highline		Govt. Orchard Mesa				Adjacent to River		Redlands			
	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha
Irrigated Cropland	20,733	8,397	6,774	2,743	28,097	11,379	320	130	1,568	635	57,492	23,284
Farmsteads	685	277	234	95	1,477	598	5	2	69	28	2,470	1,000
Suburbs/ Residential	100	41	652	264	1,384	561	---	---	700	284	2,836	1,149
Idle	2,100	851	928	376	4,972	2,014	---	---	607	246	8,607	3,486
SUBTOTAL	23,618	9,565	8,588	3,478	35,930	14,552	325	132	2,944	1,192	71,405	28,919
Urban	743	301	703	285	5,540	2,244	44	18	677	274	7,707	3,121
Stockyards	200	81	182	74	394	160	---	---	40	16	816	330
Industrial	---	---	---	---	642	260	83	34	---	---	725	294
Natural Ponds	635	257	135	55	866	351	2,107	853	63	26	3,806	1,541
Phreatophytes	6,554	2,654	850	344	6,568	2,660	5,181	2,098	1,191	482	20,344	8,239
Precipitation Only	10,429	4,224	964	390	3,979	1,612	722	292	1,235	500	17,329	7,018
TOTAL	42,179	17,083	11,422	4,626	53,919	21,837	8,462	3,427	6,150	2,491	122,132	49,463

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[1] Land Use Survey, Bureau of Reclamation, 1973.

TABLE 4. USE OF IRRIGATED LAND FOR CROPS, GRAND VALLEY, COLORADO, 1969 and 1973 (Leathers, 1975)[1]

	Colorado River								Private Systems[4]				Gunnison River Private Redlands				TOTAL			
	Government Highline				Government Orchard Mesa				1973		1969									
	1973[2]		1969[3]		1973		1969										1973		1969	
	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha
Corn (Grain & Ens.)	6,316	2,558	5.979	2,422	861	349	767	311	6,548	2,652	7,511	3,042	168	68	124	50	13,893	5,615	14,381	5,824
Sugar Beets	2,004	812	3,452	1,398	---		51	21	1,578	639	1,726	699	---		32	13	3,582	1,451	5,261	2,131
Sm. Grains	2,710	1,098	2,622	1,062	78	32	355	144	3,599	1,458	4,354	1.763	73	30	73	30	6,460	2,616	7,404	2,999
Alfalfa	6,292	2,548	7,019	2,843	1,242	503	948	384	5,815	2,355	6,262	2,536	526	213	531	215	13,875	5,619	14,760	5,978
Hay Grass	951	385	450	182	128	52	233	94	2,414	978	1,855	751	---		31	13	3,493	1,415	3,569	1,445
Pasture	2,005	812	1,591	644	1,589	644	741	300	5,627	2,279	5,165	2,092	614	249	1,254	508	9,835	3,983	8,751	3,544
Orchard	200	81	695	282	2,681	1,086	3,493	1,415	2,071	839	2,403	973	180	73	371	150	5,132	2,078	6,962	2,820
Truck Crops	34	14	287	116	161	65	197	80	94	38	360	146	7	3	38	15	296	120	882	357
Turfgrass	45	18	---	---	---	---	---	---	113	46	---	---	---	---	---	---	158	64	---	---
Grass Seed	148	60	---	---	---	---	---	---	76	31	---	---	---	---	---	---	224	91	---	---
Other	28	11	126	51	34	14	---	---	162	66	17	7	---	---	---	---	224	91	143	58
TOTAL	20,733	8,397	22,221	9,000	6,744	2,731	6,785	2,740	28,037	11,379	29,653	12,009	1,568	635	2,454	994	57,172	23,115	61,113	24,751

[1] Land use criteria used for these studies varied considerably, an effort was made to make them comparable.

[2] Land Use Survey, Bureau of Reclamation, 1973.

[3] Walker and Skogerboe, 1969.

[4] Does not include land irrigated directly from river.

water tables to rise. In addition, there has been loss of irrigated land to urbanization. The City of Grand Junction has grown significantly and has required land area formerly used in crops production.

Waterlogging and salinity problems led to studies of irrigation efficiency in the 1950's. Valleywide efficiencies of only 39 to 40 percent were documented. Average river diversions were found to exceed 600,000 acre-feet (74,000 ha-m) annually. Crop requirements were estimated at only 175,000 acre-feet (21,600 ha-m) annually. Low priced project water contributed to wasteful use. The studies caused little change in irrigation practices.

Costs of production are suggested by the data in Table 5. These data were developed for a study of land and water use in agriculture in the Grand Valley and reflect production costs and crop prices in 1973.

SOCIAL CHARACTERISTICS

Human Ecology

The Grand Valley is essentially rural in nature, with Grand Junction serving as the urban hub. Situated in Mesa County, the Valley is comprised of people of which 3.6 percent of the population are farmers or farm managers. The median years of education for the population is 12.2 years for men and 12.3 years for women. Unemployment rates are 5.8 percent for males and 4.8 percent for females. The median income if $8,065 while the per capita income is $2,658 (Appendix A). Urban growth is expanding fairly rapidly, the rural farm population is declining, and the majority of the farm land is owned by independent, family-size farm operations.

These are some of the critical parameters that one looks at when attempting to introduce an innovation into a social system. Thus, this description of the social characteristics will entail those aspects of the social situation that are deemed important when looking at the possible implementation of an innovative program for improving irrigation return flow quality. This description will first look at the degree of urbanization and growth in the Valley, and then look at three conditions within the Valley: 1) the rural farm population and the rural nonfarm population; 2) the type of farm organization; and 3) a description of the farm operation. From these parameters, a picture of the social situation that any innovation will have to encounter will emerge, and these will be the facilitators and constraints of any implementation policy.

A little less than half of the Valley's population lives in urban areas (47.8 percent) and most of those people live in Grand Junction (20,170). The growth rate of the Valley as a whole is moderate (7.2 percent), and Grand Junction's growth rate is commensurate with the country's rate. Further growth will depend on tourism and the exploitation of natural resources like coal, oil shale, natural gas, and petroleum. However, projections speculate that the city of Grand Junction will increase its 1970 population of 20,170 to about 31,400 by the year 2000, and the county as a whole will inhabit 100,000 people at that time.

TABLE 5. CROP PRODUCTION COSTS AND RETURNS, GRAND VALLEY, COLORADO, 1973.*

Crop	Unit	Average Yield Per Acre	Unit Price	Forage Value of Crop Residue Per Acre	Total Gross Revenue Per Acre	Operating Costs Per Acre	Net Return Per Acre
Corn (grain)	Bu.	115	$2.50	$11.00	$298.50	$160.89	$137.61
Small Grains:							
Malting Barley	Bu.	65	$3.00		$195.00	$114.20	$ 80.80
Milling Wheat	Bu.	70	$2.65		$185.50	$105.97	$ 79.53
Sugar Beets	Tons	21	$30	$6.00	$636.00	$318.75	$318.25
Permanent Pasture--7 months pasture rent @ $15/mo/ac					$105.00	$ 89.20	$ 15.80
Alfalfa Hay	Tons	4.5	$45	$9.00	$211.50	$118.98	$ 92.52

* Leathers, K.L. (1975), "The Economics of Managing Saline Irrigation Return Flows in the Upper Colorado River Basin: A Case Study of Grand Valley, Colorado." Unpublished Ph.D. Dissertation, Department of Economics, Colorado State University, Fort Collins, Colorado.

The first condition within the Valley that will influence an innovation is the situation regarding the rural nonfarm population and the rural farm population. Rural farm is defined by the census as residents living in a place of ten acres (4 ha) or more from which sales of farm products of the preceding year amount to $50 or more, or a place less than 10 acres (4.05 ha) from which sales of farm products of the preceding year amount to $250 or more. In short, this definition distinguishes a population who utilize the land in a different manner.

This rural nonfarm population has an equivalent level of formal education as that of the rural farm population, it has a higher median income, and a higher per capita income (Appendix A). Approximately 28 percent of the rural farm population are farmers or farm managers, while only 3 percent of the rural nonfarm population are farmers or farm managers. The rural nonfarm population is increasing slightly while the rural farm population is dropping (Appendix A). These two populations will generally perceive their relationship to the land somewhat differently and this will carry over into the management of their irrigation system.

A second condition describes the type of farm organization (Appendix A). The most prevalent form of management of a farm unit is the independent or family-farm organization. This includes not only the number of farm units, but also the acreage under control. Partnerships are the next most predominant unit while corporate farms generate some impact in the area.

Another aspect of the farm organization is the tenure system of the operator. Tenure of the operator has been defined by the Census in three ways: 1) full owners--who operate only land they own; 2) part owners--who operate land they own and also land they rent from others; and 3) tenants--who operate land they rent from others or work on shares for others. In the Grand Valley, the full owner farms greatly outnumber the other type of tenured farms, but this type of farm in terms of acreage falls just below the part-owner farms. These part-owner operators can be part-time farmers, farmers renting land from other retired or elderly farmers, or they may be managers of other farms. Therefore, here are two additional types of farmers who will view their operations and any innovations brought to them from different perspectives.

The third condition that directs how an innovation will be received is the operation of the farm; i.e., the amount of irrigation utilized and the productivity of the farm. The category that contains the largest number of farm units is the one with the size of the units being 10-49 acres (Appendix A). Yet, the concentration of acres irrigated are contained in the units whose size ranges from 260 acres to 1,000 acres (105-405 ha). Again, two possibly different perspectives on farming and irrigating may be present. There are enough farm units that cover the whole range of farm sizes that innovations must take this diversity into account.

In addition, the productivity of the farm unit will determine to some extent how an innovation will be accepted. The Valley's largest category is classified as part-time, those farm units that earn $50-$2,499 of farm product sales and are run by operators who are under 65 years of age and work off the farm 100 days or more in the census year (Appendix A). The largest category contains the farms that produce from $2,500-$7,500 per year. In addition to these two distinguishable areas of concentration,there are a significant number of farms spread throughout the income categories. Therefore, in introducing an innovation, while the two main categories should be the focus of concentration, one cannot simply center the attack on these groups alone.

In summary, Grand Valley is a rural area that is experiencing moderate growth. The farm units are mostly owned by independent, family-farm organizations of which most--approximately 88 percent--utilize irrigation. A vast majority of the farms are smaller units with the larger operations on the western side of the Valley. At the center of this Valley is Grand Junction. A future concern to this Valley that will have some effect on irrigation return flow quality is the potential energy development that will probably take place in the near future.

Institutional Setting

The organizational framework affecting irrigation in the Valley discussed in this report focuses around the Grand Valley unit of the Colorado River Basin Salinity Control Project (CRBSCP). This project is a result of the Colorado River Water Quality Improvement Program which is designed to "provide for programs upstream from the Imperial Dam (Arizona) necessary to stabilize the salinity of the Colorado River." The project is the first study conducted to determine the effect of a salinity management practice in the Grand Valley on the quality conditions of the Colorado River. The following section will discuss the different organizations involved with this project (see Figure 9).

The CRBSCP has two focuses: action and research. Two plans of action have been considered to control salinity: 1) the Water Systems Improvement Program (WSI); and 2) the Grand Valley Irrigation Management Services (IMS). The main purpose of WSI is to line canals and laterals, and construct measuring devices at all the turnouts from the canals to the laterals. For the IMS, on-farm improvements are the critical features. The improvements include lining ditches, automating delivery systems, use of sprinklers, and most important, irrigation scheduling. This program is planned to increase irrigation efficiencies from approximately 33 percent to approximately 60 percent.

The Bureau of Reclamation was named by Congress as the organization responsible for this action program (P.L. 93-320, the Colorado River Basin Salinity Control Act). Studies have been made by the Bureau to establish a salinity control program in the Grand Valley since 1972, and were to be completed by June 30, 1976. An Environmental Impact Statement on Salinity control for the basin has also been prepared. The Bureau's plan is to have an extensive program of canal and lateral lining which would be financed 75 percent by the Federal Government in nonreimbursable funds, and which would have the remaining 25 percent split between the Upper Basin and the Lower Basin, each obtaining the funds through their power contracts. The total cost of this program was estimated at around $75 million in 1975.

The Bureau contracted with the SCS to look at the on-farm management aspect of the salinity problem. A report by the SCS on this situation was

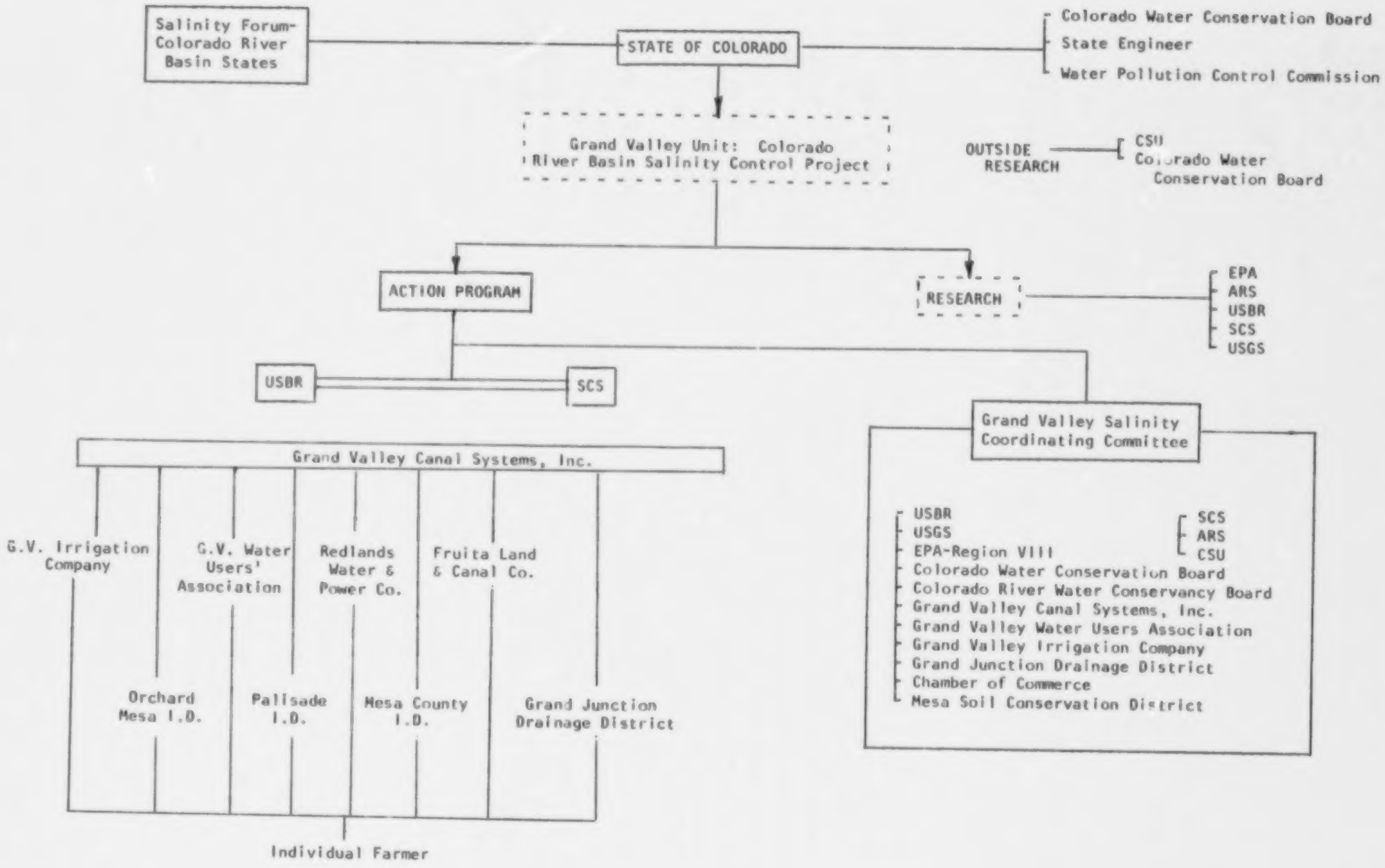
Salinity Forum-
Colorado River
Basin States
STATE OF COLORADO
Colorado Water Conservation Board
State Engineer
Water Pollution Control Commission
Grand Valley Unit: Colorado River Basin Salinity Control Project
OUTSIDE RESEARCH
CSU
Colorado Water Conservation Board
ACTION PROGRAM
RESEARCH
EPA
ARS
USBR
SCS
USGS
USBR
SCS
Grand Valley Salinity Coordinating Committee
USBR
USGS
EPA-Region VIII
Colorado Water Conservation Board
Colorado River Water Conservancy Board
Grand Valley Canal Systems, Inc.
Grand Valley Water Users Association
Grand Valley Irrigation Company
Grand Junction Drainage District
Chamber of Commerce
Mesa Soil Conservation District
SCS
ARS
CSU
Grand Valley Canal Systems, Inc.
G.V. Irrigation Company
G.V. Water Users' Association
Redlands Water & Power Co.
Fruita Land & Canal Co.
Orchard Mesa I.D.
Palisade I.D.
Mesa County I.D.
Grand Junction Drainage District
Individual Farmer

Figure 9. Organizational representation of salinity program in Grand Valley.

due at the end of June, 1976. The projected cost of this program has been estimated at $28 million, of which $7 million has already been defined as being implemented previously by farmers' improvements. It is not known at this time where the funds for this program are to be obtained. A program of action to improve on-farm management is seen to begin tentatively in the Fall of 1977. The critical concern of the Bureau with regard to on-farm management, and therefore the thrust of the program, was set to be with irrigation scheduling. The question of cost sharing still needs to be resolved for on-farm improvements.

In 1967, irrigation interests in the Grand Valley became concerned with the potential financial responsibility to the Valley by downstream salinity damages, and formed the Grand Valley Water Purification Project, Inc., in 1968. It consisted of various irrigation companies and districts and was formed to deal with the Federal Government on the salinity control demonstration project involving canal lining. After completion of the first grant, the corporation reorganized in 1972 as a new association named the Grand Valley Canal Systems, Inc. With the same goals, this association comprises a number of organizations: 1) the Grand Valley Irrigation Company; 2) the Grand Valley Water User's Association; 3) the Redlands Water and Power Company; 4) the Orchard Mesa Irrigation District; 5) the Palisade Irrigation District; 6) the Mesa County Irrigation District; and 7) the Grand Junction Drainage District.

Four of the irrigation entities divert water directly from the Colorado River: 1) the Grand Valley Irrigation Company; 2) the Grand Valley Water User's Association; 3) the Palisade Irrigation District; and 4) the Mesa County Irrigation District. The Redlands Power and Water Company diverts water from the Gunnison River and the rest of the companies have carriage agreements with the major companies for delivery of water. The various companies in the Valley serve areas as large as 46,678 acres (18,905 ha), of which 29,727 acres (12,039 ha) are agricultural cropland under the Grand Valley Canal Company to agricultural croplands of 608 acres (246 ha) under the Mesa County Irrigation District.

In addition to Grand Valley Canal Systems, Inc., another organization was developed in response to the salinity situation: the Grand Valley Salinity Coordinating Committee. The purpose of this Committee is "to eliminate duplication of effort and bring about a better understanding of salinity control programs." This Committee is made up of numerous Federal, state and local groups interested and involved with the various salinity control programs (see Figure 9).

Some of the responsibilities of the major organizations include conservation programs on the farms--the Mesa Soil Conservation District, ASCS, and the SCS. Organizations involved with on-farm management practices include Colorado State University, the U.S. Bureau of Reclamation, USDA Agricultural Research Servcie, Colorado Water Conservation Board, and the local entities. These on-farm management practices include automated irrigation systems, canal and lateral lining and irrigation scheduling.

Other agencies are strictly concerned with the second aspect of this Grand Valley Salinity Control Demonstration Project: research. The USDI, Geological Survey's main concern is to provide other working agencies with streamflow and water quality information needed to assess salt load conditions. Other research money is going to the USDI, Bureau of Reclamation to measure application rates and their relation to salinity output, to the Colorado Water Conservation Board for study of automated systems, and to Colorado State University for various kinds of salinity research, to name a few.

Emanating from this Salinity Control Program, numerous organizations have performed many tasks. Some tasks have been with regard to research while others take on a more action-oriented posture. It is hoped that these efforts will combine to reduce salinity in the Colorado River.

LEGAL CHARACTERISTICS

Historical Aspects of Colorado Water Law

Colorado is an appropriation doctrine state. Even before the acquisition of statehood, the common law riparian doctrine had been rejected (see language of Coffin v. Left Hand Ditch Co., 6, Colo. 443, 1882). Colorado was the very first state to adopt a pure appropriation system; thus, the term "Colorado Doctrine" was coined to delineate this water law system from later modifications found in other western states.

The Colorado Doctrine is set forth in the State Constitution,which declares that the unappropriated water of every natural stream is the property of the public, subject to appropriation, and the right to divert unappropriated waters of any natural stream to beneficial uses shall never be denied (Colo. Const., Art. XVI, Secs. 5 and 6). Another Constitutional expression of the appropriation doctrine is found in Article XVI, Sec. 6, which provides that as between those using water for the same purpose, priority of appropriation shall give the better right.

These Constitutional expressions have been supplemented by legislation, which states that:

> All water originating in or flowing into this state, whether found on the surface or underground, has always been and is hereby declared to be the property of the public, dedicated to the use of the people of the state, subject to appropriation and use in accordance with law (C.R.S., Sec. 37-82-101, 1973).

In the early development of the prior appropriation doctrine, a water right was created by a diversion of water and the application of the water to a beneficial use. This right was placed in the priority system by a decree from a judge. Failure to have the right decreed rendered it junior to those who had adjudicated rights (Hardesty Reservoir, Canal and Land Co. v. Arkansas Valley Sugar Beet and Irrigated Land Co., 85 Colo. 555, 277 P.763, 1929). If a water right was perfected before the adoption of the recording system, it was not affected (Larimer and Weld Reservoir Co. v. Fort Collins Milling and Elevator Co., 60 Colo. 241, 152 P.1160, 1915).

This system of adjudicating rights by judicial decree was modified in 1969 with the passage of the Water Right Determination and Administration Act (C.R.S., Sec. 37-92-101, et. seq. as amended). This Act will be discussed in further detail in the next section. Basically, the Act created special water courts and made some administrative changes in the water rights system.

Water quality control did not find its origin in state law. Rather, it began through the efforts of the Federal Government in controlling discharge into navigable waterways. The Rivers and Harbors Act of 1899 granted jurisdiction of discharge control to the Army Corps of Engineers. The first significant Federal legislation for water pollution control was enacted in 1956 (Federal Water Pollution Control Act of 1956, P.L. 83-660.0, July 9, 1956). Numerous amendments and specific laws on water pollution were enacted during the next 15 years, but in 1972 the theory and scope of water pollution enforcement were drastically revised with the passage of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500, Oct. 18, 1972). This law expanded Federal enforcement to interstate waters and adopted a two-pronged enforcement approach based upon water quality standards and effluent discharge limitations.

In 1966, the Colorado Water Pollution Control Act was enacted to prevent, abate and control the pollution of the state's waters and to establish stream standards. This law was amended in the following year to allow for the adoption of effluent standards in order to rectify particular discharge problems that exceeded stream standards. These amendments also created the Colorado Water Pollution Control Commission to administer the law.

In 1973, Colorado adopted the Water Quality Control Act of 1973 (C.R.S., Sec. 25-8-101 to 25-8-704, 1973). This act was passed in recognition of the fact that the pollution of state waters was a menace to public health, a nuisance to the public, harmful to wildlife and aquatic life, detrimental to beneficial uses of waters of the State, and in close interaction with water pollution problems in adjoining states (C.R.S., Sec. 25-8-202(1)). These acts and their administration will be examined in greater detail in a later section.

State Quantity Laws

In General--

The state constitution provides that the unappropriated water of every natural stream is the property of the public dedicated to the use of the people of the state and subject to appropriation (Colo. Const. Art. XVI, Sec. 5). Furthermore, the constitution states that "the right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied" (Ibid., Sec. 6). Between those using water for the same purpose, the first in time is the first in right and the use of water for domestic purposes is preferred over agricultural uses, which is in turn preferred over manufacturing purposes (Ibid.).

Any appropriative right is a right to possess and use the water as opposed to an ownership of the corpus and is characterized as an interest in real property-- an usufruct. It is a vested and valuable property right which is given protection by the state constitution (Town of Sterling v. Pawnee Ditch Ext. Co., 42 Colo. 421, 94 P. 339, 1908), but it is subject to certain limitations and conditions of use. Coupled with every right is a corresponding duty. Used in a context relating to water law, the duty is to use the water beneficially or without waste. The term usufructuary must be limited to defining one's corresponding duty to the water. The word "duty" is the correlative of a right. Thus, wherever there exists a right in any person, there also rests a corresponding duty upon some other person or upon all persons generally (Ibid).

An appropriation is the intent to take the water accompanied by some open physical demonstration (Elk-Rifle Water Co. v. Templeton, 173 Colo. 438, 484 P.2d 1211, 1971). The appropriation is made when the act evidencing the intent is performed (Ibid.). Thus, when a user indicates an intent to take the water for a beneficial use by some open, physical demonstration and then actually applies the water to the designated use, an appropriation arises (Ibid.).

An appropriator is required to have a reasonable means of diversion and he cannot command the whole flow of a stream just to aid his taking a fraction of the whole flow to which he is entitled (Colorado Springs v. Bender, 148 Colo. 458, 366 P. 2d 552, 1961). In Fort Lyon Canal Co. v. Chew, the court held that an appropriative right could not be enlarged or extended beyond an amount beneficially needed and used for the original undertaking for which the priority was awarded. Thus, a priority will be enforced against junior appropriators only to the extent of that water which has been historically needed and used by the senior appropriator (Enlarged Southside Irr. Ditch Co. v. John's Flood Ditch Co., 116 Colo. 580, 183 P.2d 552, 1947).

Appropriators are entitled to a supply in the order of their priority. Thus, the most senior appropriator is entitled to his quantity without interference (Comstock v. Ramsay, 55 Colo. 244, 133 P. 1107, 1913), even if his right is for storage for future use (People v. Hinderlider, 505 P.2d 894, 1936), even when there is insufficient water in the source of a common supply to meet the demands of junior appropriators (Strickler v. Colo. Springs, 16 Colo. 61, 26 P. 313, 1891).

The appropriation of water for future use under the conditional decree system was liberalized in a series of 1950-1967 cases. The change occurred in the doctrine of relation back where major transmountain diversion projects are involved. Relation back has been defined as:

> ...that operation by which the appropriation of water relates back to the time when the first step to secure that appropriation was taken, if the work from that step on was prosecuted with reasonable diligence (Taussig v. Moffat Tunnel Water And Development Co., 106 Colo. 384, 106 P.2d 363, 1940).

This doctrine developed in response to the problem created by large projects in which water rights could be lost due to the delay in applying the water to a beneficial use. The right given is a conditional right which ripens into a permanent right upon completion of the project and application of the water to a beneficial use.

Beneficial Use--

Beneficial use was defined by the General Assembly in 1969 as:

> ...the use of that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which appropriation is lawfully made and without limiting the generality of the foregoing includes the impoundment of water for recreational purposes, including fishery or wildlife (C.R.S., Sec. 37-92-103).

Uses recognized as beneficial are domestic, agricultural, industrial, municipal, and recreational (Colo. Const. Art. XVI, Sec. 6). Denver v. Sheriff (105 Colo. 193, 96 P.2d 836, 1939) held that an appropriator cannot divert more water than he reasonably needs for his intended beneficial use. The court went on to say that the amount depends upon the nature, place and time of use and varying duties of water can be established dependent upon circumstances of each case (City and County of Denver v. Brown, 56 Colo. 216, 138 P.44, 1914). Thus, the concept of beneficial use prescribes the types of uses and the basis for determining or measuring the water right. An appropriative right cannot be enlarged or extended beyond the amount beneficially needed and used for the original undertaking for which the priority was awarded (Ft. Lyon Canal Co. v. Chew, 33 Colo. 392, 81 P.37, 1905).

Abandonment and Forfeiture of Water Rights--

Colorado has no forfeiture statute but a water right can be lost by abandonment, adverse possession, condemnation, and by the power of eminent domain. Abandonment procedures are instituted by either civil suit or through administrative initiative by the State Engineer. When an appropriator has failed for a period of ten years to apply his water to a beneficial use, a rebuttable presumption of abandonment arises (C.R.S., Sec. 37-92-402, Sec. 37-92-103). Administrative procedures for the operation of administrative abandonment are set forth in C.R.S., Sec. 37-92-402.

Abandonment of a water right means the termination of water right in whole or in part as a result of the intent of the owner to discontinue the use permanently (21 Colo. 357, 40 P.989, 1895). To abandon means "to forsake; give up wholly; quit; to discontinue, desert, relinquish, surrender, vacate, or give up" (Putnam v. Curtis, 7 Colo. App. 437, 431 P.1056, 1894). The mere nonuse of a water right does not work an abandonment (Fruit Growers Ditch Res. Co. v. Donald, 97 Colo. 264, 41 P.2d 516, 1935), but in the New Mercer Ditch Co. v. Armstrong Water Commission (21 Colo. 357, 40 P.989, 1895), the court held that an appropriator cannot for an unreasonable time hold water for speculative purposes and make no beneficial use of it or divert more than he needs for the purpose for which the diversion was made.

The party who seeks to prove the abandonment has the burden of proof (White v. Nuskolls, 49 Colo. 170, 1910). When a priority has been abandoned other users on the stream can appropriate such waters in the order of their priorities (North Boulder Farmers Ditch Co. v. Legett Ditch Res. Co.). If a water right has been obtained by deed, then abandonment cannot take place until sufficient time has passed to create a prescriptive right in another user, which is 20 years (Fruit Growers Ditch Res. Co. v. Donald, loc. cit.). A period of 40 years of nonuse has been held to be prima facie evidence of an intent to abandon (Ibid.). Justification for nonuse may exist if economic, legal, or financial problems or natural disaster prevents the use of decreed waters (Colorado River Water Conservation District v. Twin Lakes Reservoir, 506 P.2d 1226, 1973).

Surface Waters--

The previous discussion applies to both surface and ground water rights in general. The following materials focus specifically upon the acquisition and administration of surface waters.[1]

As was previously stated, a right to use water can be initiated by diversion and application of unappropriated water to beneficial use. A person who wants a determination of a water right and the amount and priority thereof must file an application with the water clerk (C.R.S., Sec. 37-92-302). Any person who wishes to oppose an application must file with the water clerk a verified statement of opposition which sets forth the facts as to why the application should not be granted or granted in part or on certain conditions (Ibid.). In determining a water right, standards to be considered are: 1) that the priority date awarded shall be that date on which the appropriation was initiated if the appropriation was completed with reasonable diligence; 2) change of a water right will be approved if the change will not injure owners of vested rights; and 3) substituted water must be of a quality and quantity to satisfy the requirements of senior appropriators (C.R.S., Sec. 37-92-305). The flow chart shown in Figure 10 illustrates the procedures to be followed in adjudication of a water right in Colorado.

Priority is determined in an adjudication proceeding before a water judge. An application is made to the division water clerk and may be referred to a referee or decided by a water judge. Priority means "the seniority by date as of which a water right will be entitled to use and the relative seniority of a water right or a conditioned water right in relation to other water rights and conditional water rights deriving their supply from a common source."

Ground Waters--

Little legislative or court action is found concerning ground water in the early history of Colorado due to the lack of extensive use of ground water supplies until recently. The first legislative step toward controlling ground water occurred in 1953, following the Supreme Court's finding in Safranek v. Limon (123 Colo. 330, 228, P.2d 975, 1951) that Colorado water law was deficient with respect to ground waters. The law authorized ground water studies and required filing well logs.[2]

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[1] See Evolution and Administration of Colorado Water Law: 1876-1976, by Radosevich, et al., Water Resources Publications, Fort Collins, Colorado, 1976.

[2] See David L. Harrison and Gustav Sandstrom, Jr., "The Groundwater-Surface Water Conflict and Recent Colorado Water Legislation," University of Colorado Law Review 43, 1971.

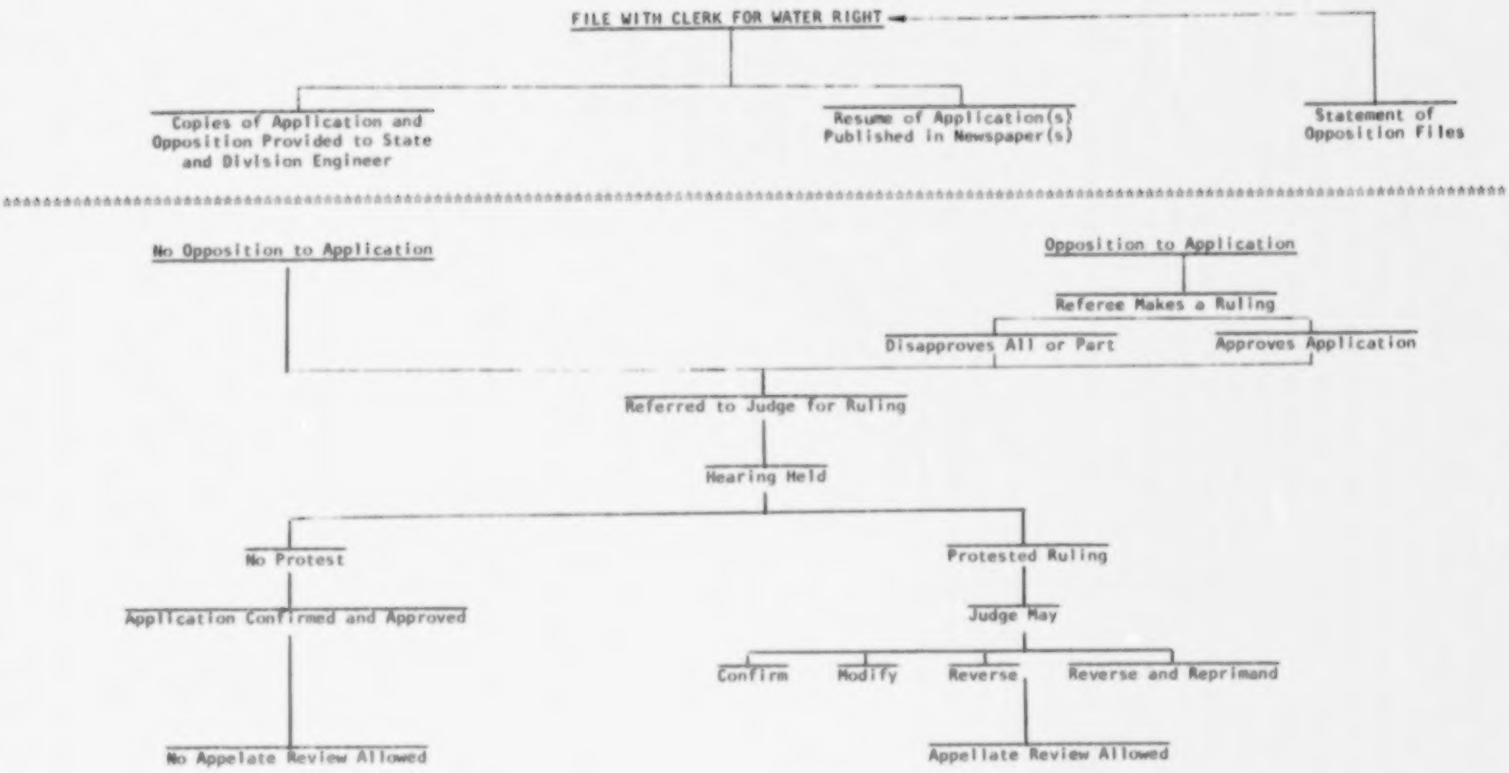
FILE WITH CLERK FOR WATER RIGHT
Copies of Application and Opposition Provided to State and Division Engineer
Resume of Application(s) Published in Newspaper(s)
Statement of Opposition Files
No Opposition to Application
Opposition to Application
Referee Makes a Ruling
Disapproves All or Part
Approves Application
Referred to Judge for Ruling
Hearing Held
No Protest
Protested Ruling
Application Confirmed and Approved
Judge May
Confirm
Modify
Reverse
Reverse and Reprimand
No Appelate Review Allowed
Appellate Review Allowed

Figure 10. Application of adjudication procedures for water rights in Colorado.

However, it was not until 1957 that the first "ground water law" was passed. This law was applicable to all subsurface waters (Law of May 1, 1957, Colorado Session Laws, 863). The four major provisions of the law were: 1) by July, 1960, all ground water users must file statements with the State Engineer, setting forth such information as the nature, extent, location, and quantity of their withdrawals and use; 2) a ground water commission was created; 3) the commission had the power to designate "tentatively critical ground water districts in areas where the withdrawal of ground water appears to have approached, reached, or exceeded the normal rate of replenishment;" and 4) no new wells could be drilled or the supply from existing wells increased without first obtaining a permit from the State Engineer. The law set the basic institutional framework for ground water allocation and management in Colorado. But, due to the particular limitation for maintaining an area as "critical" under the 1957 Act, it was repealed and reenacted in 1965 (Moses and Varnesh, 1966).

The present statutory status of ground water laws in Colorado is the result of two major legislative enactments in subsequent amendments to the basic acts. In 1965, the "Ground Water Management Act" was adopted (C.R.S., Ann., Sec. 148-18-1 to 38, 1965, Supp., now cited as C.R.S., Sec. 37-90-101 to 141). It primarily addressed the nontributary waters. The lack of specific legislation or judicial guidance for tributary waters and the emerging problems in the Arkansas, South Platte and Rio Grande Valleys led to the enactment of the Water Right Determination and Administration Act of 1969 (C.R.S., Sec. 37-92-101 to 602). Aside from sweeping changes in the process of water administration and the introduction of a tabulation system, the 1969 Act attempted to fill the gap in legislation by addressing the tributary ground water issue. These two acts are consistent with an early Colorado decision recognizing two categories of ground water: 1) tributary ground water; and 2) nontributary ground water (Medano Ditch Co. v. Adams, 29 Colo. 317, 66 P.431, 1902). The court held the former refers to waters that, if left to flow, will become part of a natural stream, and the latter refers to waters which will not become part of any natural stream.

There are four key procedural features of the 1965 Act which enable the state to allocate and manage designated ground waters. They are the reinstitution of a permit system for acquiring rights to withdraw and use designated ground water (C.R.S., Sec. 37-90-107), the creation of the Colorado Ground Water Commission within the Division of Water Resources to designate ground water basins and determine the allocation and administration of waters within the basins (C.R.S., Sec. 37-90-104), the granting of authority and jurisdiction over administration and distribution of waters and protection of vested rights to the State Engineer with the flexibility of enabling his office to grant permits for small capacity wells in deep aquifers (C.R.S., Sec. 37-90-105 and 137), and finally, the authority to form water management districts to continue the administration and management of waters within designated ground water basins (see C.R.S., Sec. 37-90-118 to 135 for the procedures to organize a ground water management district).

Any person desiring to appropriate ground water for a beneficial use in a designated ground water basin is required to make application to the Ground Water Commission. The Commission will make a preliminary evaluation of the application and notify other water users by publication in a local newspaper of the application. If no objections are filed and the Commission feels that no damage will be caused by the well and that it will not contribute to unreasonable waste, it shall direct the State Engineer to issue a conditional permit (C.R.S., Sec. 37-90-107).

Having received a conditional decree from the State Engineer, the applicant must proceed with "due diligence" in the construction of the well and apply the water to a beneficial use (C.R.S., Sec. 37-90-107). If all requirements of the Commission have been met and the water has been put to a beneficial use, the Commission will direct the State Engineer to issue a final permit to use designated ground water at a given rate.

Concerning the priority date established for wells, the law states that "priority of claims for the appropriation of designated ground water shall be determined by the doctrine of prior appropriation" (C.R.S., Sec. 37-90-109(1)). Prior to the enactment of the above-mentioned article, the effective date of the appropriation was based on the actual removal of designated ground water and its application to a beneficial use. Subsequent to the passage of the appropriate sections, the effective date of an appropriation is based on the date of filing an application with the Commission.

The right to use water under a permit from the Ground Water Commission is for use only upon the lands designated in the application (C.R.S., Sec. 37-90-107(1)). These water rights are thus appurtenant to specific lands and cannot be used to irrigate other lands without first receiving authorization from the Commission.

Tributary Ground Waters--

During the past decade, Colorado has experienced conflicts over the use of surface and tributary ground waters and attempts of resolution through litigation and legislation. Basically, the law protects senior water rights and optimum use of the State's water resources. But, in the early 1950's, the law was deficient or unable to resolve two key areas of conflict: 1) determination of priorities between surface and well water users; and 2) determination of priorities and rights between well water users. The 1965 Ground Water Management Act resolved the major issues of water allocation and administration for non-tributary waters, but the tributary water problem was still to be faced.

The current law governing tributary water within the State was passed in 1969 and is known as the "Water Rights Determination and Administration Act of 1969." The legislative declaration of the Act acknowledges the interrelationships of ground and surface waters:

> It is the policy of this state to integrate the appropriation, use and administration of underground water tributary to a stream with the use of surface water in such a way as to maximize the beneficial use of all the waters of this state (C.R.S., Sec. 37-92-102(1)).

To carry out this policy, and in full recognition of the inadequacy of past laws on the subject, the legislature set out the following principles to be applied in developing a sound and flexible program of integrated water use in the State. They are:

1. All previously vested rights and uses protected by law, including an appropriation from a well, shall be protected (C.R.S., Sec. 37-92-201(1)).

2. The present use of wells, either independently, or in conjunction with surface rights, shall be given the fullest possible recognition. However, this principle will be limited to existing vested rights. Each diverter must establish a reasonable means of diversion and he cannot command the whole flow to take his appropriation (C.R.S., Sec. 37-92-201(2)(c), 1973).

3. Use of a well may be an alternative or supplemental source for a surface decree (C.R.S., Sec. 37-92-301(3)(a)(b).

4. No junior appropriator can be limited unless this reduction would result in an increased water supply available to the senior appropriator (C.R.S., Sec. 37-92-502(2)).

The significance of the 1969 Act, aside from its setting policy to integrate the surface and ground waters of the State, is the approaches and procedures it advocates. The Act creates a unique system of water administration in the State with various power divided between the water courts established in each of the seven water divisions and the Office of State Engineer and the division engineers. The courts approve applications for water rights and adjudicate such rights while the State Engineer and his staff have responsibility for administration and distribution of the waters of the State. Since under the doctrine of prior appropriation water shortages require shutting off junior diversions, the ultimate effect upon most well users is restricted pumping. However, the law provides the opportunity for water users to develop an "augmentation plan" to prevent strict regulation under priorities (C.R.S., Sec. 37-92-307). Other important features of the law provide for obtaining an alternate point of diversion (C.R.S., Sec. 37-92-301(a) and (d)), adjudicating wells (C.R.S., Sec. 37-92-601), and exempting certain wells from adjudication requirements (C.R.S., Sec. 37-92-601).

State Water Quantity Agencies and Administration

There are several Colorado agencies that have a direct interest in water administration, but only three line agencies have direct control over the water resources at the state level.[3] These three agencies are:

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[3] See: Clyde-Criddle-Woodward, Inc., Report on Colorado Water Administration, Denver: Colorado Dept. of Natural Resources, 1968, p. 14. Much of the administrative information reported here is based on this study.

1. The Division of Water Resources (State Engineer);
2. The Colorado Water Conservation Board.
3. The Colorado Water Pollution Control Commission.

In addition, Colorado introduced special "water courts" in 1969 which decree water rights and resolve "water matters" within this jurisdiction.

The Division of Water Resources--

The Division of Water Resources is within the Department of Natural Resources and is administratively headed by the State Engineer. It is composed of a Water Operations section, Engineering section and Hearing (or Legal) Section. The Water Operations Section administers the use and distribution of the State's surface and ground water and is broken down into the Ground Water and Surface Branches. The Engineering Section provides technical support for administration in the fields of records and files, hydrography, hydrology, and dams and reservoirs. This section, in turn, is broken down into the Records, Dams and Reservoirs, Hydrographic and Investigation Branches. The Hearing or Legal Section is responsible for advising the State Engineer and coordinating legal matters surrounding the Colorado water problems and conflicts.

Colorado is typical of most of the Western states in that it depends on a State Engineer to administer its water control functions. The principal responsibility of the State Engineer "is to administer the laws...pertaining to water rights and, at the request of the Governor, to render service and give counsel to other agencies of the state" (Clyde-Criddle-Woodward, 1968, p. 15). The Governor appoints the State Engineer, pursuant to Article XII, Section 13, of the constitution of the State of Colorado" (C.R.S., Sec. 37-80-101). He must be a person qualified to be a registered engineer in Colorado with knowledge and experience in areas essential to the proper discharge of his duties and functions (C.R.S., Sec. 37-80-113(1)(a)). He reports to the Executive Director of the Department of Natural Resources. He is the executive officer in charge of supervising the work of all division engineers and has executive responsibility and authority with respect to: carrying out the terms of compacts and judicial orders; securing and implementing legal opinions and assistance regarding the work within his jurisdiction; coordinating the work of the division of water resources with other departments of the state government; supervising employees in the office of the division of water resources; preparing and keeping records and investigations as related to the functions of the division, including water well licensing; making rules for the division of water resources; supervising the measurement, recordkeeping, and distribution of the public waters; and collecting and distributing data on snowfall and prediction of probable runoff. The State Engineer has authority to delegate any other person to the obligation to discharge duties imposed upon him (C.R.S., Sec. 37-80-102(1-8)). Finally, he is a member of the Western States Water Council, Board of Examiners, Water Well and Pump Installation Contractors, Colorado Ground Water Commission, Colorado Water Conservation Board, and Irrigation District Commission. He has also been appointed the Commissioner of the Rio Grande River, Republican River, La Platta River, South Platte River, and Costilla Creek Compacts.

To assist the Office of the State Engineer in administering the State's waters, seven water divisions were created for the nine drainage basins in the State in 1969, thereby eliminating the previous 70 districts. Water distribution and administration of laws at division and local levels are carried out by a division engineer and his staff. The former is appointed by the State Engineer (C.R.S., Sec. 37-92-201 and 202).

The seven division engineers have been directed to prepare tabulations, in order of seniority, of all decreed water rights and conditional water rights in their respective divisions. These tabulations are subject to the approval of the State Engineer. They are to describe each decreed water right and conditional water right and to set forth the priority and amount thereof as established by court decrees. The priority lists are separated so that only those water rights and conditional water rights which take or will take water from the same source, and thus are in a position to affect one another, will be on the same priority list.[4]

This system of tabulations was developed to alleviate much of the difficulty in resulting litigation from uncertainty among owners of water rights in Colorado. Earlier problems had arisen as a result of transfers of water rights with no record of the original owner or transfers. However, problems in maintaining current ownership of water rights have caused disappointment with the effectiveness of this program.

Water Courts--

As noted above, the Water Right Determination and Administration Act of 1969 established seven water divisions in Colorado. The State Engineer appoints one Division Engineer for each district. The Supreme Court of Colorado is also required to designate or redesignate a Water Judge for each division to hear all water matters in the division (C.R.S., Sec. 37-92-203). Each judge is directed to appoint such referees as may be needed, and the referees are required to possess the training and experience to enable them to render the expert opinions and decisions on water matters. Additionally, under the Act each Water Division Office has a Water Clerk (C.R.S., Sec. 37-92-204). His duties are to maintain records related to appropriation, determination of water rights, plans for augmentation, abandonment of water rights and conditional water rights, and the records of all proceedings of the Water Judge.

The referees have the authority and duty to rule upon determinations of water rights and conditional water rights and the amount and priority. They rule on changes of water rights, approval of reasonable diligence in the development of appropriations under conditional water rights, and determinations of abandonment of water rights or conditional water rights. They may include combination of uses, and points or methods of diversion, any place or alternate places for storage, and may approve any change of water rights (C.R.S., Sec. 37-92-301(2)). The referee is an aid to the court and his findings, though not absolutely binding on the court, guide the inquiry and affect the result. Where the district judge has made findings, the power of the water referee to submit suggested contradictory findings is limited by the requirement that there be evidence to support the action of the referee. He may not lawfully make findings on the identical evidence used by the Water Judge, or contradict and overturn the court's decision without having received additional evidence.

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[4] See Michael D. White, "A Guide to the Examinations of Water Tabulation," 47 Denver Law Journal, 213, 1970, for a short article which could help to safeguard water rights.

Colorado Water Conservation Board--

The Colorado Water Conservation Board was established to aid in the protection and development of the waters of the State for the benefit of the present and future inhabitants of the State (C.R.S., Sec. 37-60-102). The Board consists of 13 members. The Natural Resources Coordinator, Attorney General, State Engineer, and Director of said Board are ex officio members. The remaining members are appointed by the Governor for terms of three years.

It is the duty of the Board to promote the conservation of the waters of Colorado, to secure their greatest utilization and prevention of floods. In particular, the Board has the power to foster and encourage irrigation districts, water users' associations, conservancy districts, drainage districts, mutual reservoir and irrigation companies, grazing districts, and any other agencies which may be formed under Colorado laws. It is to assist these entities in their financing, but not to lend or pledge the credit or faith of the State of Colorado or to attempt to make the State responsible for any of their debts, contracts, obligations, or liabilities thereof. The Board is to devise and formulate methods, means and plans for bringing about the greater utilization of the State's waters, to gather data and information looking toward the greater utilization of the waters, and to cooperate with the United States and other states for the purpose of bringing about the greater utilization of the waters of the State of Colorado and the prevention of flood damage.

The Board can file applications to appropriate water in the name of the Department of Natural Resources and take all action necessary to acquire or perfect water rights for projects sponsored by the Board.

The Colorado Water Conservation Board has been directed to make, or cause to be made, a continuous study of the water resources of the State of Colorado. It shall also carry on a continuous study of the present and potential uses thereof to the full extent necessary to a unified and harmonious development of all waters for beneficial use in Colorado to the fullest extent possible under the law, including the law created by compacts affecting the use of said water (C.R.S., Sec. 37-60-115). The State of Colorado has assented to the provisions of the "Water Resources Planning Act," approved by the U.S. Congress on July 22, 1965 (C.R.S., Sec. 37-60-118(1)). In this regard, the Colorado Water Board was directed to conduct and establish a comprehensive water planning program, as defined in Title III of the above act, in conformity with such rules and regulations as may be promulgated by the Water Resources Council pursuant to said Act (Colorado Water Conservation Board and the Bureau of Reclamation, Colorado State Water Plan, Phase I--Appraisals of Present Conditions and Phase II--Legal and Institutional Considerations, and Phase III--Plans for Development, Denver, 1974). A provision of importance to ground water users, pertaining to both the utilization of tributary and nontributary ground waters, makes it unlawful to divert or otherwise transport such waters outside the State of Colorado (C.R.S., Sec. 37-90-136).

State Quality Law

Legal aspects of water quality are found in both the traditional "Western appropriation doctrine" for quantity allocation and statutory water quality laws. It has been noted by one author that laws developed under the appropriation system may be classified according to two major questions with respect to water quality (Meyers, 1971). They are:

1. What protection is afforded to senior appropriators against pollution by upstream junior appropriators?

2. What protection is afforded the junior appropriators against pollution by upstream senior appropriators?

Colorado has had water quality cases in each of these two groupings. These cases are discussed below, followed by a summary of the State's water quality laws.

Rights of Senior Appropriators--

This issue of the rights of senior appropriators against juniors, concerning the pollution problems, was handled in the case of Humphreys Tunnel and Mining Co. v. Frank (Colo. 524, 105 P. 1093, 1909). In this case, the plaintiff homesteaded 168 acres, part of which was irrigated by water directed from Willow Creek with a decreed priority date of July 1895, and 60 acres (24 ha) of which were natural meadowlands along the stream that grew as a result of the overflow of the stream. The defendant in 1902 began to operate a reduction mill to process various minerals. The mill was located approximately one and a half miles upstream from the plaintiff's headgate. The plaintiff contended that the continued operation of the mill would result in the destruction of his land. Based on Colorado Revised Statutes, Section 3176 and additional legislation that "prohibits any person from flooding the property of another by water or washing down the tailings of his or their sluice upon the property of other persons," the court held that the "defendant is liable in damages for this pollution of the stream which has injured plaintiff" (Ibid., p. 1095). The court held, based on the Suffolk case, which is discussed later:

> ...that it was entirely practical and feasible for the defendant, with a comparatively small expenditure and within a few weeks time, to take care of the tailings and waste material upon its own premises.

The court also set forth the opinion that the defendant, a junior appropriator in this case, does not have:

> ...the absolute right to discharge into the stream the waste water mixed with hurtful slimes, or absolve it from liability for resulting injuries to third persons who have lawfully

> acquired prior rights to use the waters thereof for any beneficial purpose, regardless of the fact that the waters used were not a part of the natural flow of the stream.

The court held that the rights of the plaintiff were subject only to the rights acquired by prior appropriators and that the plaintiff's rights were such that he should be allowed "to have the natural waters and all accretions come down the natural channel undiminished in quality as well as quantity."

Though the above case dealt with physical tailings being washed downstream, the rights of the downstream senior appropriator are clear. A much more recent case dealt with degradation in the quality of water in which there was no physical debris washed into the stream but the quality of the water was lowered.

In a recent case (Game and Fish Commission v. Farmers Irrigation Co., 426 P.2d 562, 1957), the defendant Game and Fish Commission had degraded the water by simply running the stream through a fish hatchery and returning it to the mainstream. Plaintiffs contended that this activity degraded the quality of water which was used for domestic purposes. The court held for the plaintiffs and assessed the damage at the amount which was expended to obtain a new water source. The case establishes the right to quality as well as quantity to be delivered to an appropriator but does not establish the element of quality as part of the right. That is, the owner of the right has a civil action for taking of his property but this action is only the traditional adversary action; the State Engineer has no role to play in these cases.

Rights of Junior Appropriators--

Suffolk Gold Mining and Milling Co. v. San Miguel Consol Mining and Milling Co. (Colo. App. 407, 48 P.828, 1897) concerned the right of a junior downstream appropriator against a senior upstream polluter. In this case, the Suffolk Compound in the 1880's built a stamp mill on Howard's Fork on the San Miguel River and applied the water to run its equipment and furnish water for the reduction process. After this use, the water was returned to the stream. Modifications were made to the mill in 1892 and 1893. In 1890 the San Miguel Company was organized for the purpose of furnishing power and light to the mines in the area. The company ran a pipe from Howard's Fork to its plant to operate a Pelton wheel, which furnished electrical power. After a time, the San Miguel Company noticed that its pipe and other equipment were being damaged and concluded that the Suffolk Mill above their point of diversion was responsible for the damage. The mill refused to correct the cause of the problem in response to the company's request.

The Suffolk Company claimed that they were "first comers" and as such had a:

> ...right to use the stream as they chose, and that the subsequent comer must take the water flowing down the fork as he found it when he came, and that he was without right to complain because of the pollution of the waters, or the method of user (Ibid., p. 829).

The major issue as seen by the court concerned:

> ...the title which an appropriator of the waters of this state acquires by acts duly performed under the constitution and statutes regulating its acquisition, and the rights which he does or may acquire with reference to other appropriators along the line of the stream, though subsequent in time (Ibid., p. 830).

The court noted that "an appropriator acquires a right of property in that which he has appropriated." The court went on to point out, however, that the title is necessarily subject to many conditions. The result of these conditions is that the title to this water is not absolute, rather, it is relative, and that a first comer's rights must be taken as subject to conditions and limitations.

The court, in making its ruling, stated that it would apply only to cases where part of the water was still open to appropriation. Under this condition, the court held that:

> The title and rights of the prior appropriation company were not absolute, but conditional, and they were obligated to so use the water that subsequent locators might, like lower riparian owners, receive the balance of the stream unpolluted, and fit for the uses to which they might desire to put it (Ibid., p. 832).

The court further stated that it was:

> ...practical for the Suffolk Company to have the full beneficial use of its title, and at the same time, preserve the waters unpolluted, so that they may be fully enjoyed by one who subsequently takes the water from the stream and is, as we think, entitled to it free from any pollutions which can be prevented by reasonable means (Ibid., p. 833).

The court upheld the lower court's decision that, "at a very slight expense, and at a very slight inconvenience, the Suffolk Company could prevent the injury" (Ibid., p. 833). Thus, the concept of reasonable use was adopted to deny the right of a senior to pollute the waters to the detriment of downstream juniors.

Water Pollution Control Legislation--

Prior to 1966, a water pollution control was in the Health Department with actual control a matter for local or county health officers. In 1966, the General Assembly enacted the Colorado Water Pollution Control Act to prevent, abate and control pollution of the State's waters and to establish stream standards.[5] In 1967, the law was amended to permit adoption of effluent standards to remedy particular discharge problems that exceeded the stream standards. The Colorado Water Pollution Control Commission was created to administer the law but enforcement remained a critical problem.

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[5] For an excellent discussion of water quality control under the 1966 Act, see "A Survey of Colorado Water Law," 47 Denver Law Journal, 226, 1970.

Similar problems were experienced by the Federal Government under the control and enforcement procedures called for in the 1965 and 1966 Acts. The solutions were curative and enforcement was a nightmare. Colorado followed Federal action in updating its laws and adopted the Water Quality Control Act of 1973 (C.R.S., Sec. 25-8-101 to 25-8-704, 1973; also, Radosevich and Allen, 1974). The Act was passed in Recognition of the fact that pollution of State waters is a menace to public health, a nuisance to the public, harmful to wildlife and aquatic life, detrimental to beneficial uses of waters of the State, and in close interaction with water pollution problems in adjoining states (C.R.S., SEc. 25-8-102(1)).

The Act was adopted pursuant to the declared public policy to:

> ...conserve state waters and to protect, maintain, and improve the quality thereof for public water supplies, for protection and propagation of wildlife and aquatic life, and for domestic, agricultural, industrial, recreational, and other beneficial uses (C.R.S., Sec. 25-8-102(2)).

Regarding the matters of pollution, general policy further provided:

> ...that no pollutant be released into any state waters without first receiving treatment or other corrective action necessary to protect the legitimate and beneficial uses of such waters and to prevent, abate and control new or existing water pollution and to cooperate with other states and the Federal Government in achieving these objectives (C.R.S., Sec. 25-8-102(2)).

Among the key requirements of the Act are: 1) creation of a Water Quality Control Commission (C.R.S., Sec. 25-8-201+); 2) a plan to classify state waters (C.R.S., Sec. 25-8-203+); 3) standards by which to describe water quality (C.R.S., Sec. 25-8-204+); 4) a method for promulgating water quality control regulations (C.R.S., Sec. 25-8-205+); 5) a method for reviewing the adequacy of individual sewage disposal systems (C.R.S., Sec. 25-8-206+); 6) administrative machinery to supervise loans and grants and to coordinate with other state bodies (C.R.S., Sec. 25-8-207+); 7) a chain of command for administering and enforcing water quality control programs (C.R.S., Sec. 25-8-301+); 8) a system for administratively proceeding to effect the regulations of the Commission (C.R.S., Sec. 25-8-401); 9) a permit system for the discharge of pollutants (C.R.S., Sec. 25-8-501+); and 10) enforcement provisions (C.R.S., Sec. 25-8-601+).

An important step in state water quality management was taken with the creation of the Water Quality Control Commission. This Commission consists of one member of the State Board of Health or its administrative staff; a member of the Wildlife Commission or its staff; a member of the Water Conservation Board or its staff; the Executive Director of the Department of Natural Resources or his designee; and seven citizens of the State who are appointed by the Governor. The law requires that there shall be one of these citizens from each Congressional district with the remainder from the State at large.

The Commission has responsibility for developing a comprehensive and effective program for the prevention, control and abatement of water pollution and for water quality protection throughout the entire State (C.R.S., Sec. 25-8-202(1) to (6)). In connection with this directive, the Commission's duties include classifying the State's waters, promulgating water quality standards and passing regulations to implement those standards. They are also to issue waste discharge permit regulations, supervise sewage treatment plants--both municipal and individual--review applications for underground detonations, and review these standards and regulations every three years. In October of each year, a public hearing shall be held to comment on water pollution problems within the State.

The Commission is directed to classify all State waters (C.R.S., Sec. 25-8-203(1) to (2)). The classification is to be by regulation and may use such relevant characteristics as the extent of pollution existing or the maximum to be tolerated, as a goal; source of pollution; present uses and the uses for which the water is to become suitable, as a goal; the character and use of the land bordering the water; the need to protect the water for human use, wildlife, and aquatic life; the type of water--i.e., subsurface, lake, stream, or ditch; its volume, depth, flow, temperature, and stream gradient; and the variability of such factors on a daily or average basis. It can be seen from this list that existing pollution is the thrust of concern in the classification and that the statute shall be applied to remedy pollution problems. When setting quality standards, the law requires the Commission to take into account particular water characteristics relating to pollutants and the regulations to be promulgated for their control. These pollutants range from toxic substances, through salinity and alkalinity, to suspended solids, turbidity, and temperature (C.R.S., Sec. 25-8-204(1) to (3)).

The water quality programs adopted by the Commission shall be administered by the Division of Water Quality Control of the State Department of Health of which the Commission forms a part (C.R.S., Sec. 25-8-301). The Division shall monitor for waste discharges, administer the waste discharge permit system and carry out the enforcement provisions of the statute--including seeking criminal prosecution or other judicial relief which may be appropriate (C.R.S., Sec. 25-8-302(a) through (3)).

A system of requiring a permit has been established for those persons wishing to discharge pollutants into State waters (C.R.S, Sec. 25-8-501+). An application for a discharge permit which was made under the Federal Act is deemed to be an application for a permit under the Colorado statute, however, even though permits issued under the Federal Act shall be deemed to have expired as of June 30, 1975.

Applications for permits shall be sent to the Department of Health which has discretion to issue, deny, modify, suspend, revoke, or otherwise administer the discharge of pollutants into State waters. The responsibility for issuing regulations covering permits in line with the general policy of the Act lies with the Water Quality Control Commission. The permit shall be issued unless it conflicts with a Federal or State statutory or regulatory requirement relating to the application or the proposed permit. No discharge of waste will be allowed if it will conflict with a duly promulgated State, regional or local land use plan, unless the requirements of such a plan are met or will be met pursuant to a shcedule of compliance. No permit is required by the State for agricultural wastes, flows or return flows from irrigation waters unless so required by Federal act or regulations (C.R.S., Sec. 25-8-506(1) and (2)).

Regulations enabling Colorado to participate in the National Pollutant Discharge Elimination System (NPDES) were approved by the Water Quality Control Commission on August 20, 1974. The regulations establish two state permit programs--one to control industrial and municipal discharges and another to control agricultural discharges in line with Federal guidelines for participation in NPDES. Companion regulations approved by the Commission established effluent limitations applicable to all waste water discharge except storm runoff and agricultural discharges.

Any person or agency of the Federal or State governments may apply to the Division to investigate and take action upon any suspected or alleged violation of any provision of the Act or any order, regulation or permit issued pursuant thereto. When notice has been given of an alleged violation, such notice shall be conveyed to the alleged violator. This notice shall state the provision alleged as violated, the facts constituting the alleged violation, and may include the nature of corrective action contemplated.

The Department of Health has several options open to it for remedying a violation. These include suspension, modification, or revocation of the permit (C.R.S., Sec. 25-8-604); cease and desist orders (C.R.S, Sec. 25-8-605); and clean-up orders (C.R.S., Sec. 25-8-606) which may be followed by a restraining order or injunction (C.R.S., Sec. 25-8-607) issued by the District Court in a suit instituted by the District Attorney or Attorney General. The restraining order or injunction is sought if the cease and desist order or clean-up order is ignored. In addition to the above, civil penalties of up to $10,000 per day are permitted (C.R.S., Sec. 25-8-608), as well as criminal fines (C.R.S., Sec. 25-8-609) for violation of a permit, cease and desist order, or clean-up order. Tampering with a monitoring device is punishable by a fine of $10,000, six months in the county jail, or both (C.R.S., Sec. 25-8-610).

Local Water Entities

Generally, the early Western water rights acquired considerable value as development and diversions took place. The philosophy of the prior appropriation doctrine was constantly encouraged into use in the late 1800's to 1950's with Federal policies and programs designed to settle the West and reclaim lands to agriculture.

Companies--

Where it was no longer possible or desirable for individuals to construct and operate their own diversion and delivery works, they began to form cooperative relationships which evolved into several district categories of private and quasi-public companies. The most common in Colorado is the mutual irrigation company. Mutual "water companies" are private organizations, which may be incorporated or unincorporated, organized for the express purpose of furnishing water to stockholders or to persons with vested rights in water (Farmers Water Development Co. v. Barrett, 151 Colo. 140, 376 P.2d 693, 1963). In 1969, there were a total of 1,752 mutual companies of which only 546 were incorporated (1969 Census of Agriculture, Vol. IV). These companies are non-profit entities that can levy assessments for operation and maintenance, but not charge for the water itself (Zoller v. Mail Creek Ditch Co., 498 P.2d 1169, Colo. App. 1972). The water rights held by the company are owned by the shareholders (Jacobucci v. Dist. Ct. in and for County of Jefferson, 541 P.2d 667, Colo. 1975). A mutual company can transfer, sell or lease the rights to water that it holds, but the shareholders can place restrictions on water deliveries in the company's by-laws (Model Land and Irr. Co. v. Madsen, 87 Colo. 166, 285 P.1100, 1930).

In many areas throughout Colorado, "carrier companies" are formed to deliver water from the "mutual company" to water users not within the reach of the mutual's delivery system. These companies assess their members' fees for operation and maintenance and may or may not be organized for profit. Often, ownership of shares in a carrier company is restricted to landowners adjacent to their ditches.

The second major water company is the commercial entity, organized for profit, and either owning its own water rights or delivering water for other water right holders. These entities may be classified as a public utility and subject to a higher degree of care and trust in the delivery of water to consumers (Putnam Ditch Co. v. Bijou Irr. Co., 108 Colo. 124, 114 P.2d 284, Colo. 1941).

Irrigation districts are quasi- and public organizations, formed to amass sufficient capital to construct and operate irrigation systems on a larger geographical basis than covered by irrigation companies. The distinctive feature of the district is its ability to sell bonds and levy ad valorem property taxes to raise the monies necessary for project construction and repayment. Originating as a formalized concept in California with the Wright Act of 1887, the irrigation district idea was soon adopted by the other 16 Western states as a means to improve agricultural production through development of water use potentials (Clark, 1967).

The success of this approach and the emergence of the Federal reclamation activities in the West led Colorado to adopt the Irrigation District Law of 1905 (C.R.S., Sec. 37-41-101 to 160). This Law states that a majority of landowners may petition to form a district to provide irrigation and drainage to such lands and may also cooperate with the Federal Government for construction, operation and maintenance of irrigation works. The petition is filed with the County Commissioners and, after published notice and a hearing, the district can be formed if a majority of landowners approve. Once organized, the district can acquire water, water rights and necessary properties to carry out its purposes; it can sell bonds and levy assessments against irrigated lands in the district boundaries and allocate water during periods of drought in the best interest of all parties.

The Irrigation District Law of 1921 was enacted to provide for the reclamation of lands and development of new irrigation systems (C.R.S., Sec. 37-42-101 to 160). A petition from a majority of landowners is submitted to the County Commissioners. The Commissioners transmit the proposal to the State Engineer who must prepare a feasibility study and make his recommendation to the Commissioners. If approved, the Board of Directors is elected. The district has broad powers to acquire properties and operate facilities but must adopt a definite plan to carry out the purposes of the district. It also has authority to lease surplus waters (C.R.S., Sec. 37-42-113, 117 and 135, respectively).

In 1935, an act was passed which expanded and clarified the powers and duties of irrigation districts (C.R.S., Sec. 37-43-101 to 189). This law provides, among other rights, that a district can undertake drainage activities, have preferred rights and control seepage and waste waters within district boundaries, and refuse water delivery to land upon which assessments are delinquent (C.R.S., Sec. 37-43-122,123 and 143, respectively).

Colorado laws contain two specific articles relating to formation of conservancy districts. The first--set out in Title 37, Article 1 and entitled the Conservancy Law of Colorado--authorizes the formation of districts to prevent the loss of life and properties from floods and other uncontrollable waters. Districts can be organized for any of the following purposes: 1) preventing floods; 2) regulation of stream channels or stream flows; 3) diverting, controlling, or eliminating water courses; 4) protection of public or private property from inundation (this is accompanied by broad powers to change the course of any stream by any means); and 5) conservation, development, utilization, and disposal of water for agricultural, municipal and industrial uses when desirable (C.R.S., Sec. 37-2-101(2)).

Once the district is organized and the Board of Directors has been appointed by the court, the Directors are authorized to alter, straighten, widen, deepen, or change the course of any water or water course. They may fill any abandoned water courses and may construct ditches, canals, sewers, dikes, or any other works deemed necessary to protect, operate, or maintain the works in or out of said district. They are also given broad powers to construct or renovate bridges, highways and rights-of-way or to condemn and purchase land for these purposes. They may not, however, regulate or administer water rights nor damage or take such rights without just compensation (C.R.S., Sec. 37-3-103 (1) and (2)).

The second type of conservancy district is authorized under the Water Conservancy Act of 1937 (C.R.S., Sec. 37-45-101 to 152). The need arose to provide for the formation of an irrigation-oriented water entity, at a level higher than the irrigation district, to plan and construct water projects encompassing a greater area with a basin and to provide a tax base including all lands within their boundaries, not just the irrigated lands. The water conservancy district concept was adapted to provide for the conservation of water use in Colorado for the direct and indirect benefit of the public, industries, municipalities, and irrigation water users by providing adequate and timely water supplies and stabilizing the flow of streams. Further, the districts are to strive for the highest duty of water allocated under compact and control or insure the beneficial use of all unappropriated water to a direct or supplemental use by all beneficial users (C.R.S., 37-45-101).

Grand Valley Organizations--

The present Grand Valley Canal system comprising approximately 100 miles of canals and subcanals is the result of a consolidation of the Grand River Ditch Company, Grand Valley Canal Company, Mesa County Ditch Company, Pioneer Extension Ditch Company, and the Independent Ranchmen's Ditch Association. The construction of what is now the main line Grand Valley Canal probably began in 1882 since the original priority is dated August 22, 1882, although A.J. McCune who was the engineer for the Grand River Ditch Company filed a statement with the clerk and recorder of Mesa County, Colorado, on April 5, 1883 that construction commenced January 10, 1883. At this time, the ditch was owned by Matt Arch, E.S. Oldham, William Oldham, John Biggles, and William Cline who planned for a capacity of about 786 cfs. However, the early development times were uncertain and the company, like many others, was facing financial trouble and was sold to the Traveler's Insurance Company, which also acquired title to the other four companies now making up the system. On January 29, 1894, the Grand Valley Irrigation Company was incorporated when the Certificate of Incorporation was filed with the Secretary of State's Office and the title was acquired from the insurance company.

The water rights of an agricultural area in the Western United States often are complex due to the nature of system evolution necessary to develop an area. In general, such is the case in the Grand Valley area. Upon the organization of the company, an application was made for an adjudication of its water rights from the Colorado River. The application for the Grand Valley Canal was awarded a decree of 520.81 cfs (15 cu.m/sec), July 27, 1912, with the priority date of August 22, 1882, which was priority number 1 on the Colorado River. The hearings which lead to the adjudication established an irrigated acreage of 30-35 thousand acres, with a probable 20 percent system loss rate. On July 25, 1914, the First Enlargement of the Grand Valley Canal was awarded priority number 358 and dated July 23, 1914 for 195.33 cfs (5.53 cms), of which 75.86 cfs (2.15 cms) is conditional upon the addition of 4,661.25 acres (1,887.84 ha) to the system.

Although the original decree was based on an estimated acreage of 30-35,000 acres (12,150-14,175 ha), later investigation revealed the acreage was slightly less than 40,000 acres (16,200 ha), plus the additional 4,661.25 acres (1,887.81 ha) not yet developed, for a total of about 44,000 acres (17,820 ha). If the usual 200-day irrigation season is experienced, this water right amounts to approximately 5.76 acre-feet per acre (1.76 ha-m/ha), from which an estimated 20 percent loss rate of 1.05 acre-feet per acre (0.32 ha-m/ha) leaves about 4.71 acre-feet per acre (1.44 ha-m/ha) for irrigation.

The company is organized in the corporation format. The division of water among the irrigators is on the basis of shares of the capital stock of the company comprising a total of 48,000 shares. Thus, an individual holding one share of stock would be entitled to 4.23 acre-feet (0.52 ha-m) of water at his turnout. It should be noted that this figure does not include the loss rates of the company. In addition, these figures do not include the 75.86 cfs

(2.15 cms) of conditional water. In 1971, the water assessment was $15.00 for the first share and $2.40 for each additional share. Occasionally, some assessments cannot be paid, in which case a period is given for the irrigator to reclaim the water share, after which grace period the share is sold at auction.

The Grand Valley project which now serves water to four irrigation companies--the Grand Valley Water Users Association, the Orchard Mesa Irrigation District, Palisade Irrigation District (Price Ditch), and the Mesa County Irrigation District (Stub Ditch)--is the result of considerable effort and a long series of disappointments. Before describing in detail the companies themselves, it is interesting to describe briefly the history of development leading to the present day conditions.

When the Ute Indians moved out of the Valley and the first benefits of irrigation were being realized, the opportunity for further development of irrigation above and beyond the Grand Valley could be seen. The fruit industry prospered almost from the time early settlers experimented with deciduous fruit culture that eventually gave the Valley a reputation as a high quality orchard locality. However, neither the capital nor the authorization to develop additional lands was available until 1902 when the Federal Reclamation Act was passed. Although the Act was passed, no provision for operation was made. The Bureau of Public Surveys was charged with the responsibility to investigate locations which could be developed. Early in September, 1902, J.H. Mathis arrived in Grand Junction with a small party of engineers to survey the Grand Valley for its feasibility as an experimental reclamation project.

When the investigation was almost completed, an event occurred which is probably the worst disaster to occur in the Valley. T.C. Henry, unscrupulous promoter from Denver, arrived on the scene and convinced local people he could finance, build and operate a system far better than could the government. By a majority of two votes, the local citizens accepted the proposal, causing the government to withdraw, even though the engineers had found Grand Valley to be a feasible location for a reclamation project.

In 1904, T.C. Henry was forced to admit that he had neither a plan nor a prospect for action in the Grand Valley. Fortunately, the efforts of the people were sufficient to revive government interest in the potential project. In June, 1907, James R. Garfield, Secretary of the Interior, officially approved the project and allocated $150,880 to begin the permanent survey of the project. The project at this point entailed what is now known as the Government Highline Canal and its construction was increasingly important to the local people because of the continued success agriculture had been enjoying. In fact, the future of the fruit industrylooked so promising that one six-acre peach orchard sold for $24,000 or $4,000 per acre ($59,259-9,877 per ha).

The Grand Valley was not yet through with T.C. Henry. In 1907 he contacted the Magenheimer Brothers of Chicago who had been successful in dredging operations along Lake Michigan. Since the exploitation of irrigation projects was both a popular and a successful business, they took up the line. Together with four local promoters, they organized a district (later to become the

Orchard Mesa Irrigation District) covering about 10,000 acres (4,050 ha) on the south side of the river. In addition, plans were being made by the Magenheimers to take over the remainder of the government project (Grand Valley Water Users Association).

The increasing demand for the project prompted the local people in the Association to submit a proposal to provide $125,000 if the government would match this amount for starting construction. In October 1908, Secretary Garfield accepted the challenge and approved the proposal. Local pledges in the form of work allocations were soon called upon and construction began; but at four o'clock on May 4, 1909, the same day work started, the new Secretary of the Interior, R.A. Ballenger, suspended construction with no reason stated. Ballenger had been asked by Senator Henry M. Teller from Denver to abandon the project because private capital was available for the work and in such cases the government should not interfere. This information had been given the Senator by a prominent law firm in Denver which was representing the Magenheimer-Henry combination. The local people sent representatives to Washington to investigate the work stoppage and just happened to visit Senator Teller, who then told them what had happened. Unfortunately, a great deal of effort by numerous individuals failed to sway Ballenger, who still would not give reason for his attitude. In 1911, Ballenger resigned and was succeeded by Walter L. Fisher, who finally gave his approval. And, on October 23, 1912, work was again initiated. Thus, the Association escaped falling into the hands of the Magenheimers.

The construction of the Orchard Mesa system was begun by placing a $163 per acre ($402 per ha) cost on the 10,000 acres (4,050 ha) of land with six percent interest bearing bonds and warrants. The system was so poorly constructed that portions failed before the system was completed. This was all made possible because the Magenheimers had gained control of the Board of Directors, and although the idea was met with bitter opposition by local people, the election carried. From that time on, T.C. Henry and the Magenheimers embezzled the farmers and the district to the point of final collapse. Phony construction companies, phony construction and phony personnel finally brought the district near financial collapse. Finally, an earnest plea was made to the government that rehabilitation of the Orchard Mesa system be included among construction efforts with the Association. The plea was heeded and the system saved, a cost which is still being repaid.

The efforts of T.C. Henry and the Magenheimer brothers are not unlike many that have occurred throughout the West. Many people were ruined by their actions and the memory is still very real. It is almost miraculous that the irrigation companies in the Grand Valley and many other areas are still operating. With the abbreviated history surrounding the Grand Valley Project, the operation and water rights of the four-canal system may be better understood.

Grand Valley Water Users Association--The Grand Valley Water Users Association was incorporated February 7, 1945. It operates the Government Highline Canal which serves about 44,416 acres of irrigable land. In addition, the Association diverts 800 cfs during the nonirrigation season for power development through a siphon across the Colorado River shortly below the main diversion. During the irrigation season, 400 cfs is used for power development, with the remaining 400 cfs through the irrigation pumps. The power generated with this water is sold to the Public Service Company of Colorado to help pay the debt on the original project.

The operation of the Grand Valley Water Users Association is on a corporation basis, and although stock is registered in the County Recorder's Office, none has ever been issued. The Bureau of Reclamation classified the land into one of five categories: Class 1--good orchard; Class 1A--young orchard; Class 2--good agricultural lands; Class 3--fair agricultural lands; and Class 4--poor agricultural lands. On the basis of this classification, a farmer can sign up for his irrigable acreage which allows him at the present time 4 acre-feet per acre (1.22 ha-m/ha), above which (if the supply is available) he is charged for the excess. There are restrictions on the time rate of delivery, however, which are imposed when the supply is limited. This restriction is usually a limit of 1 cfs per 40 acres (0.03 cms per 16.2 ha), and sometimes as low as 0.75 cfs per 40 irrigable acres (0.02 cms per 16.2 irrigable ha); this practice has, in the past, been necessary only during the peak use months of the summer. During the fall and spring, water is usually delivered on a demand basis. It should be further noted that although a farmer signs up for a fixed area of irrigable acreage, he may apply the water as he wishes on his property. In addition, when the property is sold he is allowed only to sell water for the irrigable acreage being sold, so in effect the water is tied to the land and nonshareholders or outside acreage cannot obtain Association water.

The price of water in the Association is based on an assessment of the irrigable acreage on the following basis:

In 1971, for example, $1.40/acre ($3.46/ha) repayment of government land;
$4.00/acre ($9.88/ha) for operation & maintenance);
$1.20/acre-foot ($9.73/ha-m) of excess used over
4 acre-feet/acre (1.22 ha-m/ha) allocated.

The minimum assessment is $20 per farm. In 1971, there were approximately 24,000 acres (9,720 ha) assessed as compared with the 25,000 irrigable acres (10,125 irrigable ha).

Orchard Mesa Irrigation District--The Orchard Mesa Division of the Grand Valley Project was formed by request of the people of the Orchard Mesa Irrigation District when the prior operation was facing bankruptcy. The district was organized under the 1905 Colorado Statute covering irrigation districts, which was later revised to the 1921 Colorado Law.

The operation of the district in many ways is similar to the Association in that the water duty and land classification are the same. The Orchard Mesa Irrigation District is now provided water through a siphon diversion from the Government Highline Canal into the Orchard Mesa Power Canal. During the irrigation season, one half of the 800 cfs (226 cms) in the canal is diverted through the Orchard Mesa Irrigation District pumps which lift 80 cfs 40 feet (2.26 cms 12.19 m) into the Orchard Mesa #2 Canal and 60 cfs 130 feet (1.7 cms 39.62 m) into the Orchard Mesa #1 Canal.

The price of using water in the District is based again on the land classification. However, the procedure is similar to the assessment technique used by county government. The Board of Directors for the Distroct prepare a budget consisting of repayment for irrigation system rehabilitation by the government, operation and maintenance, etc. Then, the budget is approved by the Tax Commission of Colorado and the State Auditor. The valuation of land is then checked with the County Assessor, from which a mill levy is set to obtain the money. In 1971, the assessed acreage was 9,199 acres, which was assessed on the following basis:

Class 1	$11.05/acre ($27.28/ha)
Class 1A	$ 8.71/acre ($21.51/ha)
Class 2	$ 8.71/acre ($21.51/ha)
Class 3	$ 7.15/acre ($17.65/ha)
Class 4	$ 5.85/acre ($14.44/ha)

Of the total revenue collected at the rate of 130 mills, 43 goes to repay the government and 87 for operation and maintenance.

Palisade Irrigation District--The Palisade Irrigation District, with essentially the same organizational format as the Orchard Mesa Irrigation District, operates the Price Ditch. This ditch is supplied 66-68 cfs (1.87-1.92 cms) through a turbine pump just off the Government Highline Canal and it exits through Tunnel No. 3. An additional 22-24 cfs (0.62-0.68 cms) is delivered through turnouts in the Highline Canal.

Both the Palisade Irrigation District and the Mesa County Irrigation District were organized independently of the government project. Their history is somewhat unknown to the writers, but they consolidated their systems with the Highline Canal when it was built, presumably to streamline their operation.

Mesa County Irrigation District--The Mesa County Irrigation District, which operates the Stub Ditch, has an irrigation water right of 40 cfs (1.13 cms). The operation and organization of this district is similar to the previous five districts mentioned. At the turbine pump serving the Price Ditch, 15 cfs (0.42 cms) is pumped into the Stub Ditch, with the remaining 25 cfs (0.71 cms) being diverted directly from the Highline Canal to agricultural lands within the boundaries of the Mesa County Irrigation District.

Redlands Water and Power Company--The Redlands Water and Power Company, a mutual ditch company, irrigates about 3,000 acres (1,215 ha) southwest of Grand Junction and south of the Colorado River. The water supply is diverted from the Gunnison River in a canal carrying 670 cfs (18.96 cms). Six cfs (0.17 cms) is used for irrigation of lands below the power canal, 610 cfs (17.26 cms) for power generation and 54 cfs (1.53 cms) is pumped to an initial height of 127 feet (38.71 m) for irrigation. Small areas in the project are served by higher lifts, the highest being at about 300 feet (91.44 m). Electricity in excess of pumping needs is sold to project settlers and to the Public Service Company.

Salinity Control Organizations--

The prospect of obtaining federal money for canal and lateral lining as a first step in salinity control in the late 1960's led to the organization of the Grand Valley Water Purification Project, Inc. (GVWPP). This was a consortium of local irrigation companies. In January, 1972, a new organization--"Grand Valley Canal Systems, Inc."--was formed. This organization has membership on the Board of Directors from the Grand Valley Irrigation Company, Mesa County Irrigation Districts, Palisade Irrigation District, Redlands Water and Power Company, and Fruita Canal and Land Company. The principal purpose of this entity is:

> To promote the efficient and proper use of irrigation water in the Grand Valley area of Mesa County, Colorado; to protect the quality and quantity of water available for irrigation purposes in said Grand Valley; to promote a cooperative effort between companies and districts distributing irrigation water through the said Grand Valley area of Mesa County, Colorado; and to do and perform all things deemed beneficial for the interest of the individual users and distributors of irrigation water in said area.

Compacts

Six major rivers and their tributaries have their origins in Colorado, providing water to eight surrounding states and Mexico. Due to this regional dependence on the waters of rivers originating in Colorado, nine separate compacts have been established between Colorado and various other states. By means of these compacts, former water problems of long duration between the states have been largely resolved. But, three such conflicts were eventually settled through actions of the Supreme Court of the United States. In this project area, our concern is only with the Colorado River and the two compacts negotiated by the basin states.

Colorado River Compact--

The Colorado River Compact--signed November 24, 1972 in Santa Fe, New Mexico--was approved by the Colorado General Assembly in accordance with the provisions of an act approved April 2, 1921. The signatory states--Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming--agreed to apportion the exclusive beneficial consumptive use of 7,500,000 acre-feet (924,750 ha-m) of water per annum. The purpose of the compact was:

> ...to provide for the equitable division and apportionment of the use of the waters of the Colorado River System; to establish the relative importance of different beneficial uses of water; to promote interstate community; to remove causes of present and future controversies; and to secure the expeditious agricultural and industrial development of the Colorado River Basin, the storage of its waters, and the protection of life and property from floods (C.R.S., Sec. 37-62-101, Article 1).

This compact defines the Colorado River Basin as including all of the drainage area of the Colorado River system and all other territory within the United States of America to which the waters of the system are beneficially applied. The Upper Basin refers to those parts of Arizona, Colorado, New

Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River system above Lee's Ferry, also all parts of said states located without and drainage area of Colorado River system which are now or shall hereafter be beneficially served by waters diverted from the system above Lee's Ferry. The Lower Basin includes the parts of Arizona, California, Nevada, New Mexico, and Utah within and from which waters naturally drain into the Colorado River system below Lee's Ferry. The Lower Basin has been allowed to increase its beneficial consumptive use of the waters by one million acre-feet per annum.

The Upper Basin agreed not to deplete the flow below 7,500,000 ac.ft. (924,750 ha-m) for any period of ten consecutive years. In addition, the Upper Basin agreed not to withhold water, and the Lower Basin agreed not to require delivery of water, which could not be used for domestic and agricultural uses. The use of the waters of the river for navigation were held to be subservient to the uses of such waters for domestic, agricultural and power purposes.

The Upper Colorado River Compact was established by the states of Colorado, New Mexico, Utah, Wyoming, and Arizona in 1948 to provide for the equitable division of the water of the Colorado River originally apportioned to the Upper Basin. The purposes of the Act are:

> ...to provide for the equitable division and apportionment of the use of the waters of the Colorado River system, the use of which was apportioned in perpetuity to the upper basin by the Colorado River Compact; to establish the obligations of each state of the upper division with respect to the deliveries of water required to be made at Lee's Ferry by the Colorado River Compact; to promote interstate comity; to remove causes of present and future controversies; to secure the expeditious agricultural and industrial development of the upper basin; the storage of water, and to protect life and property from floods.

The phrase "states of the upper division" includes the states of Colorado, New Mexico, Utah, and Wyoming. The phrase "states of the lower division" includes Arizona, California and Nevada. The Compact states in part:

> The term upper basin means those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River system above Lee's Ferry, and also all parts of said states located without the drainage area of the Colorado River system which are now or shall hereafter be beneficially served by waters diverted from the Colorado River system above Lee's Ferry.
>
> The term lower basin means those parts of the states of Arizona, California, Nevada, New Mexico, and Utah within and from which waters naturally drain into the Colorado River system below Lee's Ferry, and also all parts of said states

> located without the drainage area of the Colorado River system which are now or shall hereafter be beneficially served by waters diverted from the Colorado River system below Lee's Ferry (C.R.S., Sec. 37-62-101, Article 11(f) and (g)).

The waters of the Upper Colorado River Compact were to be divided as follows:

> A. To the state of Arizona the consumptive of 50,000 acre-feet (6,165 ha-m) of water per annum.
>
> B. To the states of Colorado, New Mexico, Utah and Wyoming, respectively, the consumptive use per annum of the quantities resulting from the application of the following percentages to the total quantity of consumptive use per annum appropriated in perpetuity to and available for use each year by upper basin under the Colorado River Compact and remaining after the deduction of the use, not to exceed 50,000 acre-feet per annum, made in the state of Arizona.

State of Colorado.	51.75 percent
State of New Mexico.	11.25 percent
State of Utah.	23.00 percent
State of Wyoming	14.00 percent

> 1. The apportionment made to the respective states by paragraph (a) of this article is based upon, and shall be applied in conformity with, the following principles and each of them:
>   a. the apportionment is of any and all man-made depletions;
>   b. beneficial use is the basis, the measure and the limit of the right to use;
>   c. no state shall exceed the apportioned use in any water year when the effect of such excess use, as determined by the commission, is to deprive another signatory state of its apportioned use during the water year...(C.R.S., Sec. 37-62-101, Article III).

Article IV held that:

> If any state or states of the upper division, in the ten years immediately preceding the water year in which curtailment is necessary, shall have consumptively used more water than it was or they were, as the case may be, entitled to use under the apportionment made by Article III of this compact, such state or states shall be required to supply at Lee's Ferry a quantity of water equal to its, or the aggregate of their, overdraft or the proportionate part of such overdraft, as may be necessary to assure compliance with Article III of the Colorado River Compact, before demand is made on any other state of the upper division.

SUMMARY

It is readily apparent that water users in Colorado are not only subjected to a host of physical and economic factors, affecting their decision to utilize their time and other resources, but that they must also be cognizant of the mechanisms that permit the use of the valuable water resources in their operation. Often, these legal characteristics of water use in Colorado are the determining factor in the conduct of the water user. Further, as time goes on, the greater pressure is placed on the agricultural sector to become more efficient, farmers will have to become more knowledgeable of the law. Many problems and their causes faced by these water users in the Grand Junction area are discussed in the next two sections.

SECTION 5

NATURE OF THE PROBLEM

WATER QUALITY STANDARDS

The reconvened Seventh Session of the "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries," with representatives from the seven basin states and the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1972), adopted the following recommendation on April 27, 1972 in Denver:

> A salinity policy be adopted for the Colorado River system that would have as its objective the maintenance of salinity concentrations at or below levels presently found in the lower main stem. In implementing the salinity policy objective for the Colorado River system, the salinity problem must be treated as a basin-wide problem that needs to be solved to maintain Lower Basin water salinity at or below present levels while the Upper Basin continues to develop its compact-apportioned waters.

Subsequent to this declaration, the Federal Government adopted the Colorado River Basin Salinity Control Act (P.L. 93-320) on June 24, 1974 with the purpose of constructing, operating and maintaining salinity control works on the lower Colorado River for users in the United States and Mexico (Hyatt, 1970). This action was followed by a policy declaration of the Environmental Protection Agency approved December 18, 1974 for salinity control on the Colorado that:

> It shall be the policy that the flow weighted average annual salinity in the lower main stem of the Colorado River system be maintained at or below the average value found during 1972. To carry out this policy, water quality standards for salinity and a plan of implementation for salinity control shall be developed and implemented in accordance with the principles of the paragraph below.
>
> The States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming are required to adopt and submit for approval to the Environmental Protection Agency on or before October 18, 1975:
>
> (1) Adopted water quality standards for salinity including numeric criteria consistent with the policy stated above for appropriate points in the Colorado River System.

(2) A plan to achieve compliance with these standards as expeditiously as practicable providing that:
  (i) The plan shall identify State and Federal regulatory authorities and programs necessary to achieve compliance with the plan.
  (ii) The salinity problem shall be treated as a basinwide problem that needs to be solved in order to maintain lower main stem salinity at or below 1972 levels while the Basin states continue to develop their compact apportioned waters.
  (iii) The goal of the plan shall be to achieve compliance with the adopted standards by July 1, 1983. The date of compliance with the adopted standards shall take into account the necessity for Federal salinity control actions set forth in the plan. Abatement measures within the control of the States shall be implemented as soon as practicable.
  (iv) Salinity levels in the lower main stem may temporarily increase above the 1972 levels if control measures to offset the increases are included in the control plan. However, compliance with 1972 levels shall be a primary consideration.
  (v) The feasibility of establishing an interstate institution for salinity management shall be evaluated.

Based upon this position and policy, the strategy for any type of development should require maintaining a net salt balance reaching the lower stem (below Hoover Dam) of the Colorado River. Thus, any development which would create an increased salinity concentration at Hoover Dam should be offset by a corresponding decrease in salinity somewhere else in the system.

EXISTING WATER QUALITY

Unfortunately, during a period of great concern for the problem of salinity in the Colorado River Basin, the impact of individual salinity sources is encompassed within the limits of measurement accuracy. In the Grand Valley area, the contributions from the Colorado and Gunnison Rivers, as well as the salt contributed by the area, is less than five percent of the mean annual flow. This allows some to suggest the Valley salt contributions and corresponding impacts of salinity control alternatives remain in question. Some insist that general data deficiencies preclude meaningful formulation of plans for local improvement or for justifying one project over another. A look at what can be said with existing data may be helpful.

There are two methods for establishing the impact an area has on water and salt flows. The first is the input-output model alluded to above, and the second is hydro-salinity modeling of the internal water uses.

Input-Output Analysis

Inflows to the Grand Valley occur as flows in the Colorado River, Gunnison River and precipitation. In addition, a small quantity of water is imported for domestic and industrial purposes, and a possibility exists that precipitation on the watershed adjacent to the Valley may contribute via diffuse ground water inflows. Neither of these latter flows are deemed significant, especially the inflow from surrounding lands because of the low annual precipitation (8-10 inches (20-25 cm)) and high evaporation demands (40-45 inches (102-114 cm)).

As a means of better identification, data for the 1968 water year (which is representative of long-term mean annual flows) from the U.S. Geological Survey (USGS) and U.S. Weather Bureau can be utilized. Inflows passing the USGS gaging stations "Colorado River near Cameo" (2,413,000 acre-feet (297,523 ha-m), "Plateau Creek near Cameo" (112,000 acre-feet (13,810 ha-m), and "Gunnison River near Grand Junction" (1,444,000 acre-feet (178,045 ha-m)) totaled 3,968,000 acre-feet (489,254 ha-m) carrying an estimated salt load of 3,070,500 tons (3,377,550 metric tons). The outflows passing the station "Colorado River at Colo-Utah State Line" totaled 3,722,000 acre-feet (458,923 ha-m) and approximately 3,771,000 tons (4,148,100 metric tons) of salt. These figures represent either published data or interpolations thereof. It should be noted that the state line station collects only limited quality data.

A comparison of the inflows and outflows indicates that 246,000 acre-feet (30,332 ha-m) of water were depleted from the system and 701,000 tons (771,100 metric tons) of salt added. Precipitation records indicate that approximately 75,000 acre-feet (9,248 ha-m) fell on the land encompassed by the irrigated boundaries of which it is estimated that 25,000 acre-feet (3,083 ha-m) could be classed as "effective on the irrigated acreages." These estimates are congruent with similar computations presented by Iorns, *et al*. (1965), Hyatt (1970), and U.S. Environmental Protection Agency (1971).

Another check on these numbers can be made from land use data collected by Walker and Skogerboe (1971) which is summarized in Figure 11. A somewhat more definite breakdown is presented in Table 6. Westesen (1974) estimated that the consumptive use based on the pan evaporation data from the U.S. Weather Bureau and calculations using the Modified Jensen-Haise method amounted to about 295,000 acre-feet (36,374 ha-m) annually, including almost 25,000 acre-feet (3,083 ha-m) of effective precipitation on other vegetative uses. Thus, the inflow-outflow data for this particular year regarding water flow is acceptable. An examination of the salt flows will be noted for comparison in the following paragraphs.

Hydro-Salinity Budgeting

The second approach to establishing the effects of water use in the Grand Valley is to model the complex interrelationships associated with irrigation and drainage. Several parameters are added to the analysis to account for the various flows which take place.

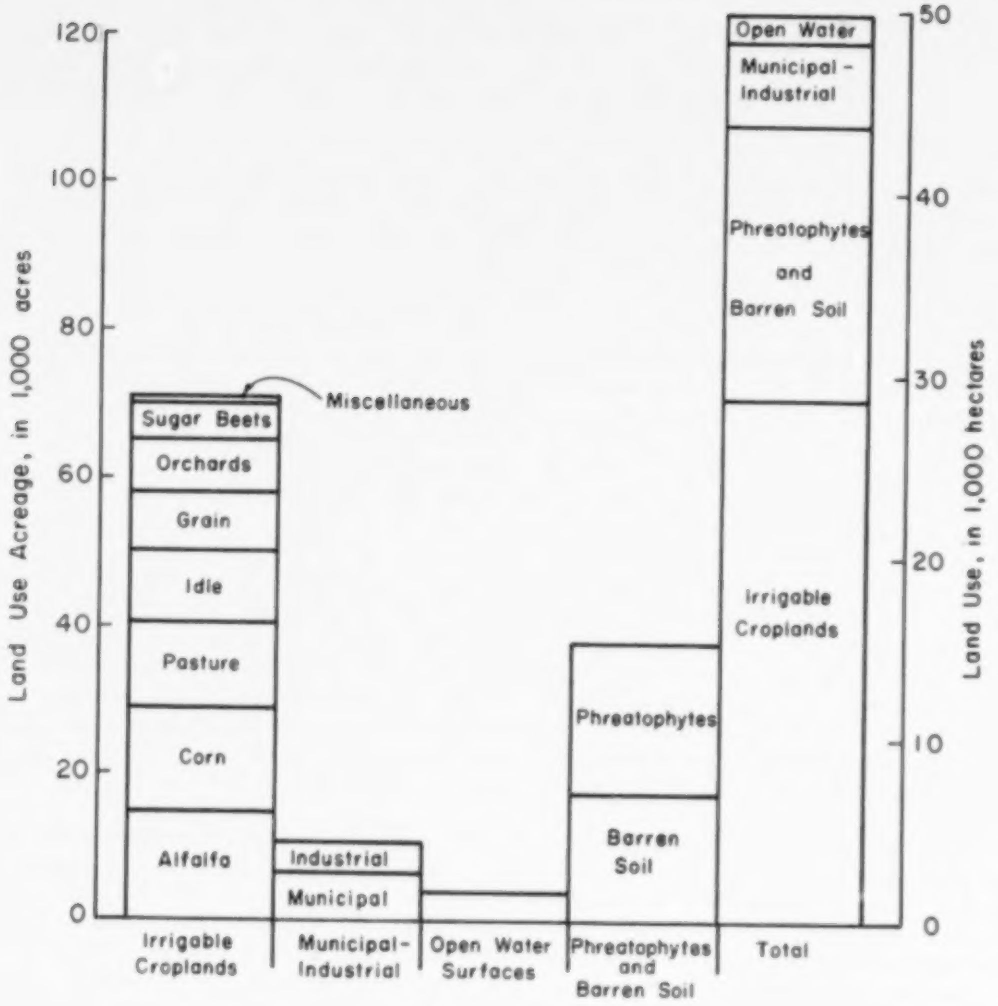


Figure 11. Agricultural land use in the Grand Valley (Skogerboe and Walker, 1972).

TABLE 6. AGRICULTURAL LAND USE IN THE GRAND VALLEY (Walker and Skogerboe, 1970).

Land Use	Acreage	Hectares	Percent of Total
Irrigated	60,844	24,642	53.0
Idle	9,706	3,931	8.5
Dwelling and Premises	10,678	4,325	9.3
Open Water	1,699	688	1.3
Phreatophyte	15,174	6,145	13.2
Natural Terrain	16,607	6,726	14.5
TOTAL*	114,708		100.0

* Roads and railways have been omitted.

The first hydrologic segment is the delineation of the canal diversions. As the water is diverted from the rivers into the canals and ditches, a certain portion of the flow seeps or evaporates from the conveyance surfaces, while still another fraction is spilled into wasteways as a means of regulating an extensive lateral system leading to the fields. It is important in this type of analysis that each flow path be defined, because each results in a different salinity effect. For example, the evaporative losses concentrate the salts in the remaining flows, whereas the seepage enters the saline ground water basin and results in salt pickup.

Lateral diversions eventually become seepage, field tailwater, root zone additions, or evaporation. In a similar manner, the root zone additions result in cropland consumptive use or deep percolation. When deep percolation is combined with seepage losses, a ground water flow segment is begun which results in the severe salt loadings common in the Valley. A great deal of the ground water is consumed by water-loving phreatophytes abundant in the area and some of the flows are intercepted by the open-ditch drainage system. A substantial amount returns to the rivers through aquifers making precise measurement difficult.

Westensen (1974) examined the 1968 water year in some detail and combined many of the principles discussed by Walker (1970) into an accounting of the flows derived for irrigation in the Grand Valley. Walker's results are shown in Tables 7, 8 and 9, presenting a valley-wide water budget, distribution of canal diversions and a salt budget.

Interpretation of Data

The budgets contained in Tables 7, 8 and 9 include some important insights to the water use practices in the Grand Valley. It has generally been the practice to state the results of budgeting procedures in terms of efficiencies, in order to extend the conclusions to other areas. Most notable, efficiencies such as conveyance efficiency, irrigation efficiency, etc., are commonly found in the literature. Since a great deal of variation can be found in the

TABLE 7. GRAND VALLEY WATER BUDGET FOR 1968 WATER YEAR
(Skogerboe and Walker, 1972).

Budget Item	Acre-Feet	Ha-m
Surface Inflows		
Colorado River near Cameo, Colorado	2,413,000	297,523
Plateau Creek near Cameo, Colorado	112,000	13,810
Gunnison River near Grand Junction, Colorado	1,443,000	178,045
Total	3,968,000	489,378
Effective Precipitation		
Cropland	25,000	3,083
Phreatophytes	5,400	666
Total	30,400	3,749
System Depletions		
Water surface evaporation		
Canals	8,000	986
Rivers	8,000	986
Phreatophyte consumption		
Along canals and drains	64,000	7,891
Adjacent to rivers	21,400	2,639
Cropland consumption	175,000	21,701
Total	276,400	34,203
Surface Outflows		
Colorado River at Colorado-Utah State Line	3,722,000	458,924

TABLE 8. GRAND VALLEY DISTRIBUTION OF CANAL FLOWS IN 1968
(Skogerboe and Walker, 1972).

Budget Item	Acre-Feet	Ha-m	Acre-Feet	Ha-m
Canal Diversions	560,000	69,048		
Spillage			103,000	12,700
Seepage			25,000	3,083
Evaporation			8,000	986
Lateral Diversions			424,000	52,279
Total			560,000	69,048
Lateral Diversions	424,000	52,279		
Seepage			51,000	6,288
Field Tailwater			162,000	19,975
Root Zone Diversions			211,000	26,016
Total			424,000	52,279
Root Zone Diversions	211,000	26,016		
Evapotranspiration*			150,000	18,495
Deep Percolation			61,000	7,521
Total			211,000	26,016
Ground Water Return Flows	137,000	16,892		
Phreatophyte Consumption			60,000	7,398
Subsurface and Drain Flows			77,000	9,494
Total			137,000	16,892

* Not including effective precipitation.

TABLE 9. SALT BUDGET FOR GRAND VALLEY DURING 1968
(Skogerboe and Walker, 1972).

Budget Item	Flow (acre-feet)	Ha-m	Concentration (ppm)	Salt Load (tons)	Metric Tons
Inflows					
Colorado River near Cameo	2,413,000	297,523	454	1,490,000	1,639,000
Plateau Creek near Cameo	113,000	13,810	454	69,000	75,900
Gunnison River near Grand Junction	1,443,000	177,921	769	1,511,000	1,662,100
Total	3,968,000	489,254		3,070,000	3,377,000
Outflows					
Colorado River near Colorado-Utah State Line	3,722,000	458,923	745	3,771,000	4,148,100
Salt Pickup				701,000	771,100

specific definitions of these terms, a discussion of terms and values in the Grand Valley is in order.

Possibly the most general measure of how efficiently water is utilized in an agricultural area is the percentage of the total diversions which are beneficially used by crops. From Table 8, it could be seen that for the Grand Valley, an efficiency of about 27 percent will be realized. This efficiency is determined by dividing the cropland consumptive use minus effective precipitation by the canal diversions. To improve irrigation efficiency, several management practices and structural improvements could be made by canal companies and irrigation districts. For example, by eliminating spillage in the system as a means of capacity management and replacing it by call periods and diversion regulation, the efficiency could be increased by 18 percent to more than 45 percent. Canal linings would further enhance this measure to almost 50 percent. The other available improvements are largely of an individual nature depending on the care and control of water by the irrigators.

Associated with the irrigation efficiency noted above are two more specific measures of conveyance efficiency. Canal conveyance efficiency and lateral conveyance efficiency may be taken as the percentages of the carried flows which reached the intended destinations. In the Valley, the efficiencies of both systems are 94 percent and 88 percent, respectively.

Once the flows reach the lateral and farm ditch systems, it is possible to attach an efficiency measure to the irrigations themselves. Skogerboe and Walker (1972) define farm efficiency as the percentage of water available to the farm which is consumptively used. Thus, farm efficiency is approximately 35 percent. This value can also be significantly improved by better water management. Specifically, the minimization of field tailwater and lateral linings could potentially increase farm efficiency to 86 percent. Certainly, a reasonable figure would be 60-70 percent if effective programs were undertaken.

Probably the most important measure of efficiency with respect to salinity control is termed application efficiency. This value represents the fraction of the flows applied to the root zone reservoir that is utilized by the crops. Its importance is that deep percolation is directly evaluated. In the Grand Valley, an average value of application efficiency is about 71 percent. The most significant improvement to this value can be made through a coordinated and effective irrigation scheduling program.

SOURCES OF WATER QUALITY DEGRADATION

The salt load added to the Colorado River as it passes through the Grand Valley is the result of subsurface irrigation return flows which take into solution the natural salts in the alluvial soils and underlying Mancos shale formation. The sources of these subsurface return flows are canal seepage, lateral seepage, and deep percolation losses resulting from overirrigation. Together, deep percolation and lateral seepage contribute 83 percent of the ground water flows. The average salinity of these subsurface return flows is approximately 8,700 mg/l, which results in a salt pickup rate of 10-12 tons per acre (22-27 m-tons/ha) annually.

PROBLEMS DUE TO EXISTING WATER QUALITY

The primary local problem resulting from poor water management is reduced crop yields on approximately 30,000 acres (12,150 ha). Agricultural land use surveys have shown salt-affected soils, abandoned irrigated land resulting from soil salinization, and once productive agricultural lands now being used for pasture because of high ground water levels. A large portion of this acreage is located along a strip of land one mile wide on the north side of the Colorado River.

Present irrigation practices result in nonbeneficial evapotranspiration losses from phreatophytes. High water tables resulting from canal and lateral seepage, along with deep percolation losses, also result in such nuisance problems as sewer infiltration, basement flooding and localized swamps which lead to public health problems associated with the production of mosquitoes.

The most serious problems resulting from the saline irrigation return flows of Grand Valley are experienced in the Lower Colorado River Basin. Increasing salinity concentrations are threatening the utility of water resources in the downstream areas of Arizona, California and the Republic of Mexico. Detriments to agricultural water users are primarily being encountered in Imperial and Mexicali Valleys, while the primary urban detriments are occurring in Los Angeles and San Diego. The U.S. Environmental Protection Agency (1971) reports that existing damages to Lower Basin users would increase from $16 million annually in 1970 to $51 million annually by the turn of the century if planned developments do not include appropriate salinity control measures, while more recent estimates of the U.S. Bureau of Reclamation (Bessler and Maltic, 1975) show present damages at $53 million annually, which is projected to be $124 million annually by the year 2000.

FUTURE WATER QUALITY CONSIDERATIONS

Mineral pollution is the most serious problem in the Colorado River Basin. The problem is serious because the basin is approaching conditions of full development and utilization of the available water resources. Thus, while the salinity problem may seem unique to basins of the arid West, it will ultimately be faced by nonarid areas as the water use approaches the available supply. Thus, the salinity control program developed for the Colorado River Basin may be expected to serve as a model for future programs in other basins, where mineral pollution is a problem.

The seriousness of mineral pollution in the Colorado River is exemplified by the history of efforts to deal with it. One prominent example was the salinity crisis of 1963 at the U.S.-Mexico border which was resolved by expenditure of "emergency" funds to construct a bypass for mineralized flows. Another example was the resolution of the seven Colorado River Basin States unanimously urging the Secretary of the Interior to defer establishment of salinity standards until a workable basin-wide mineral pollution control program could be developed.

It is obvious that the water quality problem in the Colorado River Basin has become chronic before full utilization of the water resources has been determined. The philosophy surrounding future developments will probably be one of accompanying each development with a corresponding decrease in the salt load in order to maintain present water quality levels.

The Upper Basin water users are particularly affected by these conditions because most of the future developments involve intrabasin diversions, in-basin oil shale developments and possible hydro-electric and thermo-electric production. None of these water uses add significantly to the salt loading aspect, but each diminishes the quantity of pure water available for diluting the salt loads already being carried. Consequently, future development of water resources in the Upper Colorado River Basin must be associated with more rigid salinity controls on the existing salt sources, many of which are agriculture-related.

SECTION 6

CAUSES OF THE PROBLEM

PHYSICAL CAUSES

The combination of geologic setting and an abundant water supply in Grand Valley has not only resulted in significant salt loads reaching the Colorado River to the detriment of downstream water users, but has also created significant waterlogging and salinity problems for farmers in Grand Valley. Abandoned irrigated lands and reduced agricultural productivity of the lower lands are visual evidence of these problems. Salt accumulation on the ground surface is visible at numerous places throughout the Grand Valley.

In past geologic time, the Grand Valley was overlain by an inland sea, which resulted in the deposition of salt-laden sediments. After eruption of the earth's surface and the formation of mountains, erosion of the surface marine formations occurred. Today, after considerable erosion, the Grand Valley is still underlain by a marine formation called the Mancos Shale formation. Overlying this formation are alluvial soils eroded from farther upstream and the nearby mountains surrounding the Grand Valley. These alluvial soils also contain large quantities of salts.

The Mancos Shale formation is exposed at many places throughout the Valley including the south bank of the Colorado River upstream from the city of Grand Junction, along the northern boundary of the irrigated lands in Grand Valley (e.g., the Government Highline Canal was excavated into the Mancos Shale formation at many locations along its course), and many small hills or knobs interspersed among the irrigated lands. This shale is characterized by lenses of crystalline salts which are readily dissolved by water when contacted by it.

Added to this geologic setting is a water supply which on the average is at least three times greater than the crop water requirements. Although much of this excess water returns to open drains as surface runoff, which has negligible impact upon the salinity in the Colorado River, there are still significant quantities of water that reach the underlying Mancos Shale formation. These subsurface return flows are the result of seepage losses from canals and laterals, and excessive deep percolation losses from overirrigation of the croplands.

There are two important indicators of the abundant water supply in Grand Valley. First of all, most laterals run a continuous flow rate throughout the irrigation season. Secondly, there is almost a complete lack of flow measuring devices along the laterals and at the farm inlets. Water is measured at the turnout gate from the canals into the laterals, but below these turnout structures there are usually no measurements of the quantities of water. Thus, a farmer has little knowledge of the amount of water he is using.

ECONOMIC CAUSES

Inefficiency in Water Use

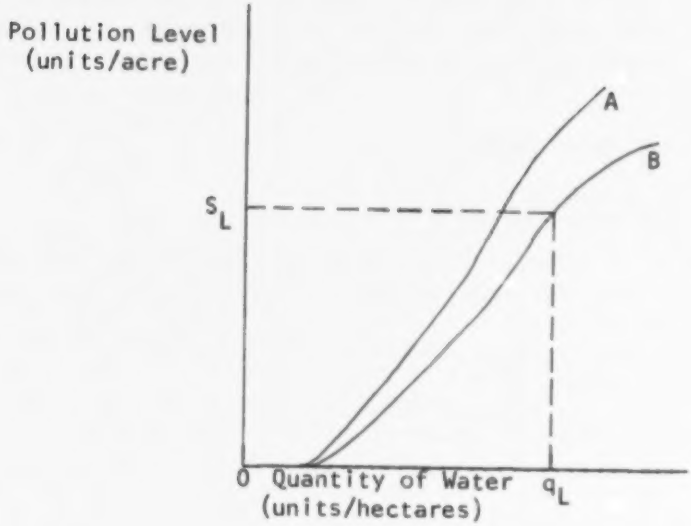
In most irrigated areas, available supplies of water are allocated among farmer-users on the basis of the rights they have established in the past. The allocation is thus established on legal rather than economic grounds. This being the case, the users tend to apply throughout the irrigation season all the water to which they are entitled. There are frequent overapplications of water to crops, water percolates into the subsoil beyond the root zone, and then moves downward into a shallow aquifer and then laterally to receiving streams. As it moves, this return flow picks up salts which occur naturally in the soils and transport them to the stream or aquifer.

Application of excessive amounts of water are attributable to allocations which exceed need, plus local water prices (conveyance costs) which are too low to encourage efficient use. This problem of price is one of ineffective reflection of the "opportunity cost" of water, i.e., its value in alternative uses. Most productive factors are allocated through markets. There is opportunity for competing users to bid for, not only the factors, but also the raw materials from which the factors are produced. So, prices of the factors reflect their alternative uses and the market allocates resources and factors so that efficient use is realized.

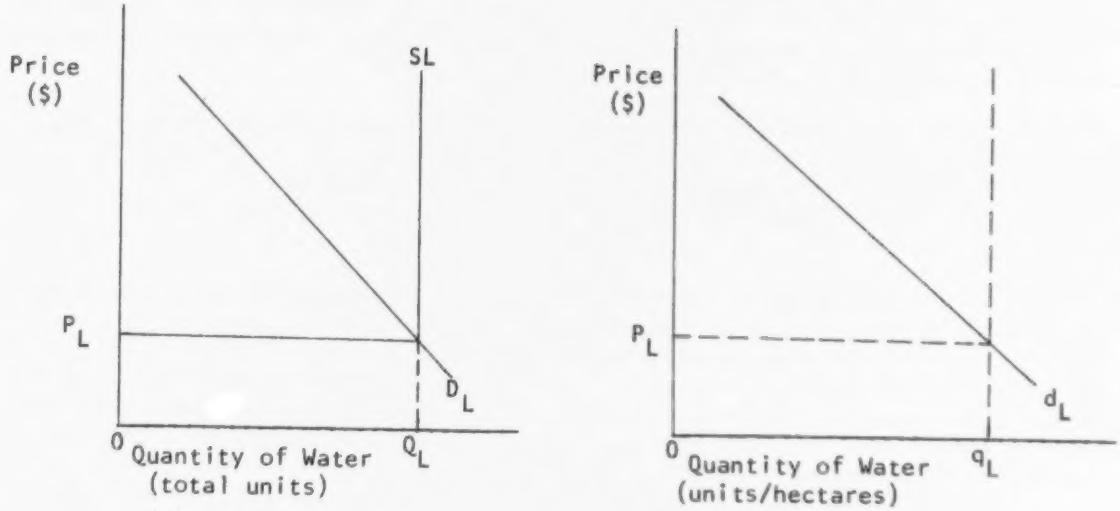
Pollution of receiving streams by irrigation return flows depends not only on excessive use of water but on other factors such as soil types, slopes of fields, types of crops, stages of growth, irrigation methods, and drainage facilities. This discussion focuses on the management and quality of irrigation water as the most critical variable.

In general, the amount of return flow pollution appears to be positively correlated with the quantity of irrigation water applied, and negatively correlated with the management of irrigation water, as shown in Figure 12(a). As water is applied beyond the consumptive use requirements of the crop (c.u.), return flow pollution tends to increase at an increasing rate with additional water up to a point of application, beyond which it increases at a decreasing rate. The relative position of this relationship depends upon the level of water management, so that curve A corresponds with a low level of management and curve B with a high level. The actual slope and shape of these curves will vary between differing areas with different physical conditions. Site-specific investigations are required to derive exact relationships; however, Figure 12(a) serves as a general principle in order to illustrate the general conceptual relationship.

Demand-supply relationships, given the allocative mechanism which now exists, are illustrated in Figure 12(b) and 12(c). Quantities of water used by farmers are then related to the pollution function in Figure 12(a).



(a) Pollution Function



(b) Market

(c) Farmer

Figure 12. Present irrigation/pollution relation.

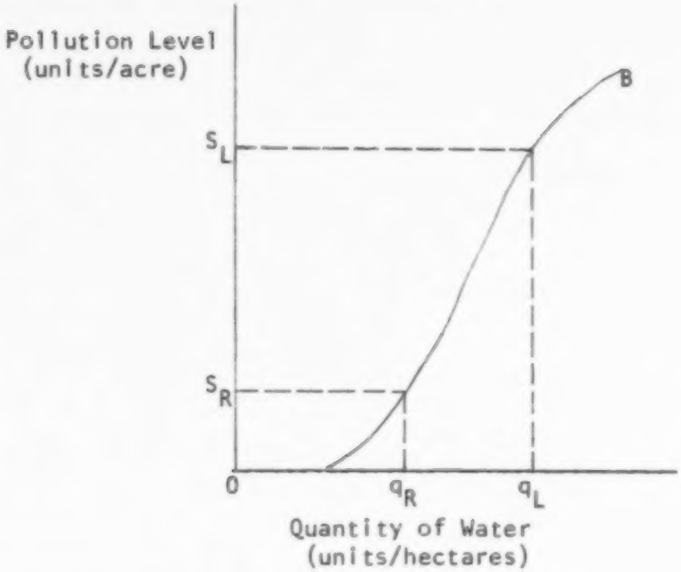
Since the appropriation cost of irrigation water is zero and the conveyance cost per unit of water is generally constant, the aggregate supply curve in Figure 12(b), S_L, under the present institutional arrangement, is a horizontal line at the level of the conveyance cost, P_L, out to the total quantity of water available for use, Q_L. At Q_L, the supply curve becomes vertical. That is, the relation between the amount of irrigation water supplied and the price of that water is a horizontal line at the level of the constant cost of conveyance up to the limit of supply, beyond which no additional water is supplied at any price. Summation of the demand of all water right holders at any point in time yields the equivalent of a market demand curve. As the demand for water in the river basin increases, the market demand curve in Figure 12 (b) shifts outward until D_L is reached. At that level of demand, the river's waters are completely allocated and no further water rights are issued.

With a normal downward sloping demand curve, d_L in Figure 12(c), the individual farmer will rationally demand q_L units of water per hectare at the average conveyance cost of P_L per unit of water. He will apply for and receive a right for the quantity as long as water is available. The actual allocation will depend on additional physical and legal considerations, but the tendency will be towards an allocation of q_L units per hectare of irrigation water. If the level of water management corresponds with curve B in Figure 12(a), then the present allocation system results in an irrigation return flow pollution level of S_L units per hectare.

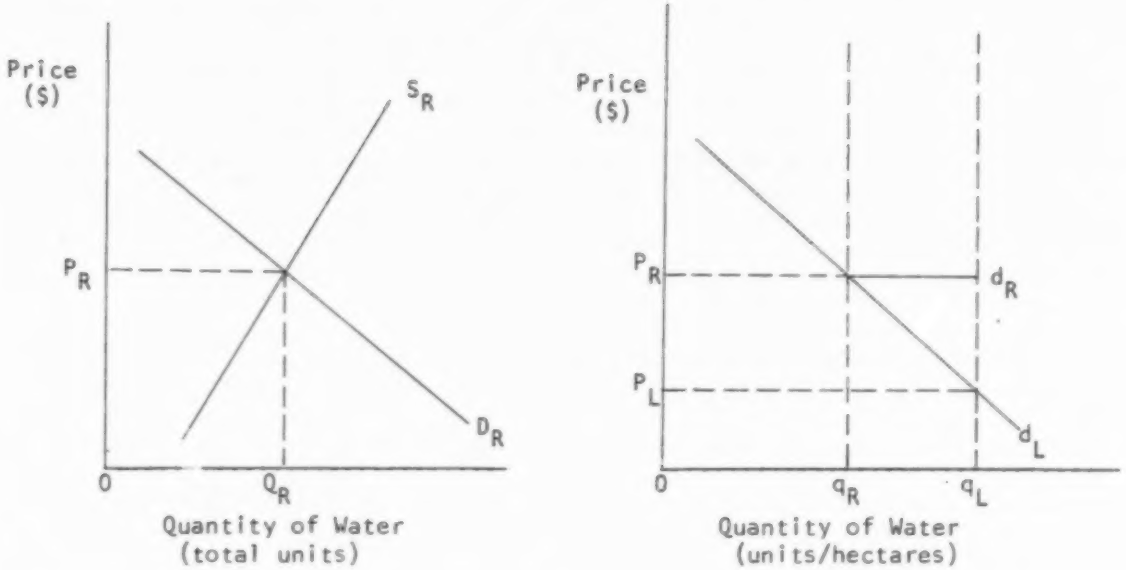
On the other hand, a market allocation of water would reduce individual farm applications of water and, consequently, return flow pollution. Suppose a water rental market is created such that nonwater right holders could rent water from those with water rights without jeopardizing those rights--conditions which will be justified later. Then, water right holders acting as suppliers of rental water would have an upward sloping supply curve, S_R, representing increasing opportunity costs as shown in Figure 13(b). This supply curve represents the quantity of water that water right holders would rent rather than use at each price. The rental market demand curve, D_R, represents the aggregate marginal value product of irrigation water to nonright holders. The equilibrium quantity, Q_R, represents the amount of water that right holders would rent to nonright holders.

Individual water right holders would adjust to the rental market equilibrium price, P_R, by reducing the quantity of water irrigated from q_L to q_R. That is, water right holders could realize a greater return from their right to q_L units of water per acre by reducing their irrigation to q_R units per hectare and renting the surplus $(q_L - q_R)$ units per hectare. The derived demand for irrigation water with a rental market, d_R, differs from the present demand curve, d_L, in that it is horizontal at the market price level beyond q_R, as shown in Figure 13(c).

If nonright holders are assumed to have identical irrigation demand curves to those with water rights, d_L, then each nonright holder will also rationally use q_R units of water per hectare at a rental market equilibrium price of P_R. The effect on irrigation return flow pollution is that each farmer would cause S_R rather than S_L units of pollution per hectare, as shown in Figure 13(a). On the other hand, there are more irrigators. The net


Pollution Level
(units/acre)
B
S_L
S_R
0
q_R
q_L
Quantity of Water
(units/hectares)

(a) Pollution Function


Price
($)
S_R
P_R
D_R
0
Q_R
Quantity of Water
(total units)
Price
($)
P_R
d_R
P_L
d_L
0
q_R
q_L
Quantity of Water
(units/hectares)

(b) Market

(c) Farmer

Figure 13. Irrigation/pollution relation with rental market.

effect of the rental market depends upon the ratio of the proportional increase in the number of irrigators to the proportional decrease in the pollution of each irrigator. If the ratio is less than one, then total pollution is expected to decline.

Externalities

Further complicating the problem of agricultural pollution of river water is the very practical ability of farmers to avoid paying the costs of the increased salinity in the return flows. There is no mechanism to force them to pay, to internalize, this production cost. In their attempt to maximize profits, they therefore do not pay the costs of pollution. They select production methods and techniques which will maximize net returns. Alternative production methods, though they may be less polluting, are rejected if they are higher in cost.

The internalization of costs of pollution (generally conceived as costs associated with reclamation of polluted waters) is depicted in Figure 14. The curve AC_1 reflects all costs of production except for those associated with salinity in return flows, i.e., pollution. Curve AC_2 includes the pollution costs and thus lies above AC_1. The curve AR represents the price of the product produced. The intersection of AC_1 and AR describes the quantity that will be produced, OQ_1, if pollution costs are unpaid. If, however, the producer is forced to internalize pollution costs, he will reduce production to OQ_2, the intersection of AC_2 and AR. The level of production OQ_1 could be maintained only if the price of the product rose to P_2.

So, any measure (e.g., a pollution tax) which forces the farmer to recognize and accept the cost associated with water quality degradation will likely cause a reduction in output. Most affected will be low value, irrigated crops which may not then be produced. Whether we should use such a measure depends on the comparative effectiveness of tax and treatment and all other measures which might be adopted to manage quality in return flows.

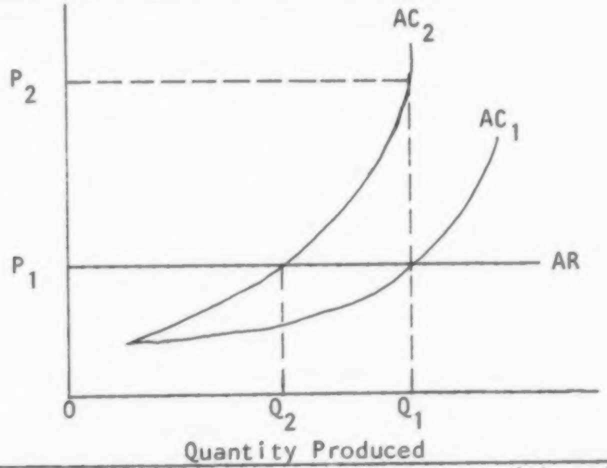


Figure 14. Costs of production of agricultural crops, with and without internalization of pollution costs.

LEGAL CAUSES

Under the American system of jurisprudence, the law is considered to be the socially acceptable mechanism to direct and control the activities of man in areas where conflict or need exist. Natural resources, and water resources in particular, have been subject to extensive legislative and judicial intervention in the attempts of man to guarantee dependability, flexibility and equity into the public and private use of the resource. Often, however, either the law lags behind social demands or it is designed to protect certain rights and privileges in conflict with those held by others. Such a situation can also arise from changing external circumstances and from the ensuing cultural lag between established practices and current conditions.

Water law, in an era of rapid social changes and of shifting emphasis to public rights and environmental concerns, is full of constraints to public interests in water quantity and quality management. In the area of irrigation return flow, the legal contributions to the quality control problems vary from state to state as the laws differ in each particular area. In the Grand Valley, a number of basic legal causes of water pollution can be identified which stem from state-wide laws to local application.

The first legal cuase is universal throughout the 17 western states, namely the failure to enforce the concept of beneficial use provisions of the law. The reason is two-fold. One has to do with the fact that the definition of beneficial use is nebulous and, thus, lacks appropriate direction for administrators to follow or courts to interpret. The second derives from a lack of social consciousness on the part of water users so that the burden of proving nonbeneficial use is upon the state, which is really an administrative impossibility. Generally, our system of water law places emphasis upon the right to use water, not the duty to use it appropriately.

Another legal problem that exists is the absence of specific responsibility or duty for water quality control by the irrigation districts and companies. Their function is primarily to capture and convey their entitled water supply to district water users. The responsibility of the irrigation companies stops at the canal turnout structures which discharge water into the laterals. An exception is the Government Highline Canal (Grand Valley Water Users Association) which maintains some responsibilities for distributing water in laterals.

Unfortunately, the water users under each lateral are in general not formally organized, which inhibits the equitable distribution of irrigation water supplies among the individual users. In the past, this situation has reflected, again, the abundant water supply in the Grand Valley. However, there are still numerous squabbles and bickering regarding the equitable distribution of water conveyed at the laterals. The irrigation companies usually refuse to become involved in such disputes. This situation is further aggravated by the lack of flow measuring structures.

A final problem results from the priority of right held by the water users. The Grand Valley Irrigation Company holds the first priority water right on the Colorado River within the boundaries of the State of Colorado. There are also many other early priority rights held by the various irrigation districts in Grand Valley. The "Cameo Demand," which is the required water deliveries as measured at a U.S. Geological Survey stream gaging station located on the Colorado River upstream from Grand Valley, is for 1,850 cfs (52 cms) during the irrigation season. These rights are for irrigation and hydropower. The large irrigation rights are partly the result of obtaining rights to irrigate more land than is presently being irrigated. This "Cameo Demand" has a definite impact upon the value of upstream junior water rights, as well as future upstream water resources development. The problem caused by senior rights (almost anywhere throughout the West under the appropriation doctrine) is that they are compelled to divert their full entitlement in order to preserve the total right. Consequently, in the case of the "Cameo Demand," and a call for water by other senior water right holders in the Valley, much flexibility for really managing the water supply is lost in an effort to preserve the water rights, even though the rights allow diversions of water in excess of what is needed to irrigate the lands under cultivation.

SOCIAL CAUSES

The problem of water quality exists in a social setting as well as in an economic and legal setting. Water users are humans, who are more comfortable with the status quo. They are jealous of their rights, uncertain about changes (usually proposed by others), unaware of certain problems of which they are a part, resistant to authority, hesitant to cooperate, etc. These characteristics, though natural, complicate management of resources in the public interest. They make correction of water pollution difficult.

The Individual Level

At the individual level, there are three general categories under which the conditions mentioned above can emerge and thus provide the impetus for the problem of water quality to continue. They are: 1) the perception by the individual of the problem; 2) the actual irrigation activity pursued by the farmer; and 3) the perception of the farmer regarding his relationship with his neighbors in terms of water quality. How the individual users fit into these categories will determine to a large extent how the problem is to be defined and then coped with.

As a whole, there is a perception by the farmers of the salinity problem, yet it is perceived in a special manner. First, it is viewed as a historical occurrence, something that is "natural" and there are people who are now asking the question, why is this salinity situation of such great concern now? In addition, many believe that much of the present problem is due to outside causes such as the trans-mountain diversion of water to Denver. In short, of those people who do perceive the problem of salinity, and not everyone does, they generally see it in terms of conditions that are not directly linked to on-farm management practices.

The second category describing the conditions that can encourage the problem situation is the actual irrigation activity pursued by the farmer. With the combination of a plentiful water supply and a legal arrangement that forces the farmers to utilize their full water right, along with some other beliefs, there is no incentive for the farmer to utilize a minimum amount of water. Besides this situation, there is differentiation made within the area between the professional farmers who do utilize their water in an appropriate manner, and those other "farmers." It also has been observed that the old time farmers will not easily change, if they do at all, but the younger farmers are more receptive to various forms of change. A large part of the problem of water management is the new part-time farmer, the suburbanite, etc., who does not know how the irrigation system runs and because of this pursues activity that is detrimental to the irrigation system as a whole. Thus, the different number and types of farmers and water users yield different management practices.

The third major category of conditions that facilitates the water quality problem is the perception of the farmer regarding his relationship with his neighbors in terms of water quality. Regarding farmers in the Grand Valley, there is a lack of a basin-wide concern over the quality of the Colorado River. Farmers still are concerned about why they have to pay the costs for problems that are a hundred miles away. In addition, while some laterals have some sort of an agreement on the managing of that water in the lateral, many more laterals are the focus of constant conflict. Therefore, proper management is hindered by a lack of user cooperation.

The Organizational Level

Regarding the organizational entities involved with irrigation, two categories emerge which facilitate the water quality problems in irrigation return flow: the integration of those organizations and their respective authority with regard to irrigation quality. It is within this organizational structure that the normative standards of behavior regarding irrigation return flow can be established to relieve this problem, and this in turn can change the various perceptions by individual users regarding irrigation return flow quality.

In the Grand Valley there already is established a framework for integration among the irrigation districts and companies, the Federal entities, the state organizations, and the farmers, due to the salinity control program. There is still some question among districts as to their authority over the use of water by the farmer on his land. Even though the integration of the various organizational entities involved has begun through the construction of various committees, the consequences of such a linkage have not yet been internalized by the farmer; i.e., that ideal of cooperation and an expected perception pattern has not been transferred to the farmer.

SECTION 7

IDENTIFICATION OF POTENTIAL SOLUTIONS

The purpose of this section is to identify potential solutions to the irrigation return flow problem in the Grand Valley. In the framework of the approach established, these solutions are initially identified with respect to the particular causes of the problem as specified in the previous section. This section concludes with a brief discussion of possible combinations of individual solutions that could deal simultaneously with several of the physical, economic, legal, and social causes of the problem.

PHYSICAL SOLUTIONS

Water entering the near-surface aquifers in Grand Valley displaces highly mineralized waters from these aquifers into the Colorado River. In any area where the water is in prolonged contact with soil, the concentration of mineral salts tends toward a chemical equilibrium with the soil. In Grand Valley, as in many other areas, high equilibrium salinity concentrations are known to exist in the near surface aquifer. The key to achieving a reduction in salt loading is to lower the ground water levels, which will result in less displacement of water from the aquifer into the Colorado River. The most effective means for lowering ground water levels is to reduce the source of ground water flows, which can be accomplished by reducing seepage through canal and lateral lining or by reducing deep percolation losses resulting from excessive irrigation by improved on-farm water management practices. Since a leaching requirement is a necessary part of local irrigation, some deep percolation losses can be expected under the most efficient irrigation practices. Therefore, tile drainage systems are also realistic salinity control alternatives when deep percolation and seepage losses, which have lower salinity concentrations than flows in the lower reaches of the ground water system, can be intercepted and removed before equilibrium concentrations are reached. Thus, drainage systems must be considered along with the other adaptable salinity control measures.

Water Delivery Subsystem

Irrigation delivery system improvements would prevent wasteage of water resulting from seepage and operational spills. Nearly all canals and most laterals in the Grand Valley are unlined. Lining of canals and lining or piping of laterals would reduce losses due to seepage and phreatophyte consumption.

The lining of laterals, or conversion to pipelines, would not only reduce seepage and consequently subsurface return flows, but would also be beneficial in providing additional water control. Another important aspect of water control is providing flow measuring devices, particularly at diversion points along each lateral and at each farm inlet. The additional water control provided by lining, or pipelines, along with flow measuring devices would have a significant effect upon farm irrigation application efficiencies.

On-Farm Water Use Subsystem

The most important element in reducing the salt contribution to the Colorado River from Grand Valley is improved on-farm management. The predominant method of irrigation is furrow irrigation. Thus, it becomes highly important that present furrow irrigation practices be modified in order to reduce the deep percolation losses that are presently reaching the shallow ground water aquifer.

Improved water application practices and scheduling of irrigation application would allow a reduction in the amount of water delivered to the farm. Present surface furrow irrigation practices on the predominantly heavy soils in Grand Valley, along with a more than plentiful irrigation water supply, result in both large quantities of tailwater runoff and deep percolation losses.

Two of the most common irrigation application methods for reducing the quantity of applied water are sprinkler and trickle irrigation. The heavy soils in Grand Valley require careful design and operation of the various types of sprinkler irrigation systems; however, this method of irrigation can be utilized when proper technical assistance is provided. Trickle irrigation is highly adaptable for use with high cash value crops, which in Grand Valley would be orchard crops; recently there have been some attempts to grow vine grapes, which would benefit from trickle irrigation.

Irrigation scheduling allows the optimum quantities of water to be applied at the optimum time intervals to conserve water and maximize economic returns. Farm returns are increased from the reduced quantity of water handled, reduced leaching of plant nutrients and erosion of topsoil, and from the reduced incidence of plant diseases associated with waterlogged soils. The reduction in soil and nutrients lost from the farm also benefits water quality.

Fertilizer applied to the soil in excess of crop requirements represents an economic loss to the farmer and causes degradation of quality of streams receiving return flow water. Both losses can be reduced by using soil analysis to determine the correct amount of fertilizer to apply, by timing applications to reduce the time available for fertilizers to be leached from the soil, and by placing the fertilizer where it is readily available to the roots. However, the most expedient means for achieving high fertilizer use efficiency is to adopt improved water management practices which provide high irrigation application efficiencies.

Water Removal Subsystem

The water removal subsystem consists of removing surface runoff from agricultural lands (if not captured and pumped back on the farm) and receiving deep percolation losses from irrigation. Tile drainage is a very effective means for removing the less saline waters in the upper portions of the ground water reservoir, thereby reducing the volume of salts returning to the river. By using tile drainage, salts are allowed to accumulate below the drains. Tile drainage will not completely remove all of the water moving below the root zone unless the water table is lowered below the natural ground water outlet. Usually, some water will still move through the ground water reservoir and return to the surface river, but the quantity of such ground water return flows can be reduced considerably by tile drainage. The quality degradation to receiving streams from tile drainage outflow can be minimized by treating the outflow. This points out another advantage of tile drainage, which is the collection of subsurface return flows.

The implementation of physical improvements in the irrigation system will require some form of incentives. Possibilities include increasing the cost of water delivered in order to make the construction of new physical facilities desirable to local water users, subsidizing the cost of physical facilities through cost-sharing arrangements, or some form of taxation.

ECONOMIC SOLUTIONS

With reference to the major economic cause of irrigation return flow pollution outlined previously, there are two respective economic solutions: 1) establishment of a market for irrigation water; and 2) internalization of production costs through taxes and/or subsidies.

Water Rental Market

A market for irrigation water can take many forms. The intent here is to identify that form which appears to be the most applicable. While the establishment of a water market will alter the present institutional arrangement, it seems desirable from a practical standpoint to alter that arrangement as little as possible in order to assure its acceptance.

In order to minimize the disruption to the present institutional arrangements for allocating irrigation water, the market form identified as having the most potential is a water rental market. Under such an arrangement, a water rental market would take as given the present structure of water rights and allotments and would permit the rental of surplus water to upstream water users without jeopardizing these rights and allotments.

A water rental market could be established by removing the present legal and physical uncertainties associated with such transfers. The hydrologic properties of the water system can readily be specified. There is a legal requirement that water transfers not injure other water rights. In most cases, transfers must be restricted to the amount previously used consumptively; however, since the return flows are not reused in the state of Colorado, there would be no downstream damages to water rights holders by transferring water upstream of Grand Valley. Such transfers will not be detrimental to downstream users so long as the state of Colorado does not exceed its entitlement to the Colorado River, which presently is not the case.

The demand for rental water would represent its addition to the total value of output per additional unit of water. The market supply schedule would represent the water right holder's increasing opportunity cost of using the water himself rather than renting it. The market equilibrium price, then, would be greater than the current costs of conveyance. Those demanding and those supplying would have an economic incentive to use water more efficiently. That is, a rental market would increase the price of water to its marginal value in production and would, thus, encourage more use of labor and capital (i.e., water management) in combination with the water, thus reducing return flow pollution.

Pollution Taxes/Treatment Subsidies

An improved allocation of water among agricultural uses would certainly be helpful to water use and to improved quality of return flows, but it would not be sufficient to correct the problem of increasing salinity of the river, for the farmer is still able to dispose of the relatively saline return flows without cost. There is no internalization of the costs associated with the polluted water. A pollution tax could be employed to cause the internalization of this cost. It would be levied so as to approximate the cost of reclamation of water to required or desired levels. Taxes could be applied to irrigation return flows directly, which would be extremely cumbersome, or could be applied through indirect relationships between water supply, crops and irrigation return flow quality that would result in higher taxes being applied to higher water delivery rates, but also taking into account the crops being grown. Proceeds from the tax would then be used either to treat the effluent (the return flow) or to develop influent controls, such as improved distribution systems, improved irrigation systems, improved cultural practices, etc. The exact form and level of a tax can be specified only for particular cases. It may be desirable to impose the tax at a level somewhat less than the pollution cost. The subsidized water management practices and capital improvements could benefit not only from the proceeds of the specific pollution tax, but also from other tax revenues. The judgment of the Congress or of state legislatures would be necessary to such decisions. But the notion of penalties and rewards, i.e., taxes and subsidies, to reduce pollution of water used in agriculture is a useful one and should be included among the alternative solutions to irrigation return flow quality problems.

Land Retirement

A more drastic approach to control of saline return flows in an irrigated area would be permanent withdrawal of water supplies. Because of the aridity of the study area, this would imply that irrigated lands would be permanently retired from the production of crops. Land retirement, either compulsory or noncompulsory, is a zero discharge control option that could be implemented in conjunction with other less costly structural and nonstructural control measures.

Water supplies could be withdrawn in two ways: first, the least productive soils could be taken out of production on a selective basis. This option would have a minimum impact on the local economy, but would not necessarily be less expensive in comparison to a second option, namely retirement of an entire block of irrigated land and service canals and laterals. This alternative could have a greater impact on the local economy, since the soils included would have a higher average productivity. However, because seepage losses would be omitted under the selective (or partial) retirement scheme, the amount of salts avoided per acre or unit area would be considerably larger with the complete retirement option (Leathers and Young, 1976).

LEGAL SOLUTIONS

The law, as a tool to guide or direct social activity relative to areas of known or potential conflict, cannot operate in a vacuum. It must be both considerate of and consistent with physical and socio-economic conditions and serve as a facilitator to a desired end result and not the reason for either achieving the problem or the solution. Unfortunately, the law often becomes a constraint as needs and conditions change, requiring amendments, additions or deletions to remove legal hindrances to the solution of water quality problems (Radosevich, 1972). For irrigation return flow quality control in the Grand Valley of Colorado, several potential legal solutions exist which would facilitate improvement of the present situation.

Beneficial Use

One of the first legal causes described above was the failure to comply with or enforce the beneficial use concept under which water is allocated and the exercise of the right to use follows. Cases in Colorado and other western states reflect the difficulty of enforcing this general concept. It is suggested, therefore, that the State Engineer's Office develop and adopt criteria for beneficial use as an agency rule or regulation. These criteria for use will in effect define the standards of water use efficiency in the conveyance and application of water under the exercise of a water right relative to quantity diversions, use and quality of discharge. They will also provide the basis for shifting the burden of proper use of the public resource upon the benefactor (both purveyor and user) and in essence identify the duty for delivery, use and removal of water.

Water Transfer Policy

A second legal solution is to merge the economic benefits from a more liberal transfer policy into legal guidelines that still provide protection to existing water rights holders. This would require the adoption of an incentive mechanism to encourage water users to "market transfer" some of their water through the irrigation districts, or possibly through the Grand Valley Canal Systems, Inc. Water could be rented or leased to upstream water users (e.g., other irrigators or new energy complexes) with the revenues being used to further improve the Grand Valley irrigation system (see Radosevich, 1972, p. 275).

Incentive Programs

Some programs already exist which provide no- or low-cost funding for improving the water delivery, application and removal subsystems. These state programs, in conjunction with the federal SCS and ASCS programs, are generally oriented toward quantity improvements. It is suggested that the water resources development funds in Colorado, administered by the Colorado Water Conservation Board, be amended to broaden its scope to: a) provide funding to individuals; and b) for not only improvements as they affect the quantity of water, but also for improvements that enhance the quality of return flows.

Water Organizations

Finally, it is proposed that water users on laterals organize into mini-companies to distribute and manage the water supply delivered them by the parent irrigation company or district of which they are members. These irrigation companies, districts and water user associations are primarily concerned with diversion and delivery of water to shareholders' laterals and maintenance of the basic system. As has been previously stated, there are often disputes within the laterals on the water distribution and very little effort to manage the water.

Thus, without going into the elaborate legal structure found in most companies, it is proposed that laterals form into executive committees with duty and right to divide, deliver and manage (prevent waste and excessive application) water delivered to the lateral. A simple agreement of organization should be signed by all water users on the lateral giving the executive committee the power to divide, deliver and manage the water, assess members for charges of the lateral and structures, and authority to cease delivery to members who abuse the organization's rules. The membership or committee should elaborate on the rules as an appendix to the basic agreement.

SOCIAL SOLUTIONS

Solutions to the problem of irrigation quality control from the social standpoint evolve from the social conditions that allow such a state of affairs to exist. Therefore, possible solutions that will produce changes in that social situation must have two points of attack: the individual and the organizational network.

The Individual

The first solution must be aimed at educating the farmers on how the irrigation system works. This may not apply to many of the older farmers, but it is perceived as a need for the newer farmers and the many suburbanites who use the system. This educational system could serve as a backdoor entrance to make the farmers more sensitive to the water quality problems. It seems that this valley has been inundated with programs, mass media coverage, and researchers all dealing with the salinity problem. Still, the perception of many farmers to the problem is not conducive to a change in on-farm management practices. Informing users as to how the system works instead of assuming that everyone is familiar with irrigation may provide the means to further explain the salinity problem in a more effective manner.

Next, an attempt should be made to organize the users along their respective laterals. There is a perceived need for greater cooperation among the users which in turn can make the system a more efficient management entity with the effect of improving the return flow quality. In conjunction with this effort, there should be more resources directed toward the SCS on-farm management program. This two-pronged attack, on the individual farmer's utilization of his irrigation water and on the lateral's cooperative use of that water, can yield practices that would enhance the return flow quality. Efforts along this line are starting to emerge and they should be strengthened and expanded in order for this program to become viable.

The Organizational Network

One final solution from the sociological perspective is to exploit the existing valley-wide organizations and committees concerned with irrigation management in such a manner as to lift them out of being a vehicle for only exhanging information and viewpoints to one of being an action-oriented group. Use one of the two groups, or combine them, and reorganize it to provide the mechanism to coordinate action programs in salinity control, give it the means to become a vehicle to implement the various programs, charge it with enforcement powers; in short, create a valley-wide authority to help in the management of the various irrigation systems in the valley. The idea behind this is to provide an organizational framework that is capable of supporting individual programs to enhance irrigation return flow quality.

In summary, the solutions that emphasize the social component of the problem are:

1. Increase the educational program on how the irrigation system is managed.

2. Organize the water users into lateral organizational entities.

3. Increase the SCS effort toward establishing improved on-farm management practices.

4. Reorganize the existing organizational structure that is created to only exchange information anc views on irrigation management to one of becoming an action-oriented entity to facilitate improved irrigation management practices.

COMBINATIONS OF SOLUTIONS

There are many possible combinations of solutions to the irrigation return flow problem. Obviously, most adjustments suggested here could not be implemented independently of other physical, economic, legal, or social concerns. Packages, or combinations of solutions, however, are difficult to construct since they tend not to be generalizable, but situation-specific. In In this respect, one cannot provide a complete listing of such combinations. Instead, some brief illustrations may show the types of mixes which would be likely and the realistic adjustments that must be made if implementation steps are to be followed.

Starting with the suggested physical on-farm improvements, it can be seen that other measures would have to be incorporated in order to create a successful program. Implementation of on-farm improvements would require an economic scheme for cost-sharing such that the distribution of benefits and costs would be equitable. Simultaneously, legal issues relating to water rights and possible changes in those rights must also be dealt with. Finally, perhaps the most difficult problem involves the social acceptance of such a plan as a result of persuasive factors for adopting changes and for establishing new practices as part of a new social context.

The suggested water rental market is not implementable without other institutional changes. It would require specification of a marketing entity and a means of determining and regulating possible downstream injuries from the transfer. Finally, physical facilities for accommodating transfers would be required, therefore, technological measures would have to be incorporated in any water market approach.

There is no need to provide exhaustive lists of examples. The point remains that there is a need for combined approaches or solutions. It is suggested by this research that further analysis of potential solutions through field testing is in order to arrive at a consensus relative to combinations of solutions. It is this last quest (and final section) that constitutes also the core argument of this research.

SECTION 8

ASSESSMENT OF POTENTIAL SOLUTIONS

Both the identification of potential solutions in the previous section and the assessment of these potential solutions to be reported below have benefited significantly from the numerous research studies and investigations that have been conducted by various state and federal agencies in the Grand Valley during the past nine years. Technological alternatives for salinity control in Grand Valley have been under investigation by Colorado State University since September 1968. Other state and federal agencies undertook additional research and investigations beginning in 1972. The Colorado State University field research was completed in November 1976 and the data analysis reported in May 1977 (Law and Skogerboe, 1977). There have also been other agencies actively involved in trying to implement a salinity control program in Grand Valley.

This particular study has been primarily concerned with the institutional aspects of the salinity problem in Grand Valley. The irrigators in Grand Valley have been exposed in recent years to the need for a local salinity control program. They displayed an awareness and knowledge of the problems involved in implementing a control program. In addition, local irrigation leaders and state and federal agency personnel were interviewed in order to benefit from their thinking and experience in assessing the potential solutions for alleviating Grand Valley's salt contribution to the Colorado River.

EVALUATION BY RESEARCH TEAM

Evaluation of Technological Alternatives

The following discussion on technological alternatives primarily relates each technology to the reduction of subsurface return flows (e.g., seepage or deep percolation losses). Recent research results (Ayars, McWhorter and Skogerboe, 1977) have shown that reductions in subsurface return flows are directly related to reduction in salt pickup and the salt load reaching the Colorado River from the Grand Valley. This subsection on technological alternatives concludes with a cost-effectiveness analysis which relates the costs of implementing various technologies to the resulting salt load reduction in the Colorado River.

Water Delivery Subsystem--

The dilemmas being faced by irrigation officials are numerous, but can be traced to one factor. When the demand for irrigation was realized and the canal alignments located, the expected demand for water was based on the total area of land under the canal. However, when the acreages of roads, homes, phreatophytes, etc., are deducted, the water available for each area is significantly increased. For example, under the Grand Valley Canal are 44,774 acres (18,133 ha) of which only 28,407 acres (11,505 ha) are irrigable. Consequently, instead of having a water duty (annual volume of water diverted from the river per unit area) of 5.76 acre-feet per acre (1.76 ha-m/ha), there is more than 9 acre-feet per irrigable acre (2.74 ha-m/ha). The result is a two-fold problem:

1. With the excess of water available to the irrigators, it is more economical to be wasteful because failure to provide adequate water to crops during critical growing periods can affect yields more than an overirrigation.

2. The history of development in the western United States has always shown water to be a valuable commodity in an area. As such, the rights one has are to be protected. Without evidence of use, i.e., diversions of water, rights can be lost. Consequently, water rights holders divert water in the Grand Valley which they do not productively use. They do not intend to be wasteful; they are simply protecting their rights.

Canals--An adequate evaluation of the operation and maintenance benefits attained from canal lining is difficult. Correspondence with officials of the Grand Valley Canal Systems, Inc., most of whom are also serving as local irrigation and drainage officials, has delineated certain benefits resulting from a canal lining program.

The linings, in addition to reducing the operation and maintenance costs, also result in other direct benefits. The moderate gradient channels, when running near capacity from April through October, experience comparatively few problems with bank vegetation, mossing and sedimentation. Records and comments from irrigation companies indicate an average maintenance cost per mile of between $250 and $370 per year in the unlined sections, depending on the canal size. In the demonstration area, the construction by CSU will probably result in a total savings of $2,500 annually. Although periodic maintenance is always necessary, there are linings ten or more years old located throughout the Valley that have as yet required almost no attention. When the canals are lined, the improvements to the delivery system for new turnout structures and measuring devices greatly aid control, distribution and measurement of water, thereby providing a stimulus to irrigators for more efficient water management.

The local benefits from the linings in many parts of the Grand Valley include factors such as improvement to adjacent lands. In a large portion of the Valley, the value of land is primarily determined by the expanding urban areas and as such do not greatly depend on agricultural production. Nonetheless, the increased utility of well-drained soils is demonstrated in the return to production when water tables are controlled and construction of basements in homes where they were not possible before.

Several qualitative statements relative to the importance of canal system improvement can be made at this point. The first aspect deals directly with the impact of better system management on the salinity problem. Almost every arid agricultural area depending upon an annually fluctuating water supply can produce evidence to substantiate the fact that during periods of diminished supply, farm production is often higher as a result of better water management on the farm. The explanation for this observation may not lie entirely in the use by the farmer, but also in the attempts to equitably allocate water among the irrigators. Thus, the irrigation company or district is the primary controller when faced with water distribution among demands which totally exceed the supply. Some evidence exists in the Grand Valley area to support the contention that more efficient management of water resulted in significant reduction in salt loading to the river (Iorns, 1965). During the years, as shown earlier, when the supply was inadequate to meet demands, the water was "rationed" and more efficient use was made. The conclusion therefore indicates that any presently proposed salinity control alternative to be implemented on a valley-wide scale must involve efficient canal management.

In order to improve canal system management, three types of changes should be implemented: 1) system rehabilitation by lining and installation of effective diversion and control structures; 2) water measurement of each user; and 3) instigation of call periods for demands. The results of incorporating these principles into the operation of a delivery system would be a surplus of water at the river diversion instead of at the canal turnout. Consequently, a large part of the water which is presently flowing as field tailwater or canal spillage could remain in the river. Two questions would need consideration: 1) What incentive is there for canal companies to leave the water in the river and risk losing their portion of their right? and 2) What use would be made of the surplus, and by whom?

Laterals--The term "lateral" refers to the small conveyance channels delivering water from company operated canals to the cropland. The extent of the lateral system was not clearly defined earlier and the effects of laterals on the area hydrology were underestimated. As a result, considerable reevaluation was made to quantify the aspects of lateral system management.

When water is turned into the lateral system, it becomes the responsibility of the users entitled to the diversion. Single users served by an individual turnout are not uncommon, but most laterals serve several irrigators who decide among themselves how the lateral will be operated. Most of the multiple-use laterals, which may serve as many as 100 users, are allowed to run continuously with the unused water being diverted into the drainage channels. This practice would be almost completely eliminated if the only water diverted was that quantity appropriated to each acre in the company water rights. The costs that would be passed on to the irrigator for a more regulated canal system would also provide added incentive for more efficient water management practices below the canal turnout. Thus, there would be an indirect economic incentive for better management.

There appears to be a considerable need for system rehabilitation in the form of linings and regulating structures prior to placing restrictions on lateral diversions. The reason is simply that little means of water distribution on an equitable basis below the canal turnout exist. Aside from the canal turnouts themselves, which could be rated individually, no observable means of measurement exists. Without adding control and measurement structures, it would be impossible to either regulate lateral diversions or distribute the water among users.

The benefits that would accrue from lining the lateral system in an area like the Grand Valley are essentially the same as described earlier concerning the canal linings. However, because of the vast extent of the lateral system, the effect of the laterals is much greater than canals. As with the canal system, the appurtenances, such as the control and measurement structures, are an integral part of any lateral system improvements. Therefore, the benefits derived from more efficient water management cannot be ignored.

Again, the formulation of salinity control measures must include, in addition to canal system improvements, lateral improvements. In fact, the delivery system in general must be rehabilitated, as well as undertaking improved operation and management practices.

On-Farm Water Use Subsystem--

"Tuning Up" Existing Irrigation Methods--There is a paucity of data for most irrigation systems in the western United States regarding on-farm evaluation of irrigation practices. The lands of the Grand Valley are no exception, except that considerable data are now being collected. Much can be accomplished by analyzing existing irrigation methods and practices on a sufficient number of farm fields so that proper advice can be given to farmers regarding modifications to existing irrigation practices that would result in both water quality benefits and increased crop production.

Traditionally, surface irrigation methods result in too much water being applied during seedling and plant emergence growth stages. This is the combined result of early season irrigation practices being similar to later irrigations when larger water applications are necessary, as well as inherent physical limitations in surface irrigation methods. However, much could be done to "tune up" such irrigation methods to allow higher early season irrigation application efficiencies. A cognizance of desirable early season improvements would undoubtedly have carryover effects into later irrigations, thereby enhancing water use efficiency throughout each irrigation season.

Field measurements are needed on farm fields throughout the Valley in order to establish the quality and quantity and timing of farm irrigation deliveries, the flow characteristics of the irrigation methods being employed (which is almost entirely surface irrigation methods), consumptive use by crops, tailwater runoff, leaching requirements, and the quality and quantity of deep percolation losses. For each field that such data are collected, recommendations can be made regarding modified irrigation practices that would more beneficially utilize water supplies and fertilizer. In addition, the use of these data in a hydrologic evaluation of each farm will allow recommendations to be made for the entire Valley. Also, the field data will show constraints being faced by the irrigator in achieving higher irrigation application efficiencies.

The results of the field studies should yield recommendations regarding a variety of physical improvements which could be undertaken to eliminate some or all of the constraints faced by the water users. These recommended physical improvements can consist of simple modifications to the existing irrigation method (e.g., concrete head ditches, employing different sizes of siphon tubes, flow measurement structure(s), gated pipes, automated concrete head ditches, etc.); conversion to new irrigation methods (e.g., converting from furrow or border irrigation to sprinkler or trickle irrigation); or could involve physical improvements in the water delivery subsystem, in particular the lateral(s) (e.g., lining the lateral, placing the irrigation water supply in a pipeline, constructing water measurement structures, improved water control structures, etc.).

Sprinkler Irrigation--A conversion from surface methods of irrigation to sprinkler irrigation systems by many of the farmers in the Grand Valley would be highly beneficial in terms of efficient water use, with the greatest benefits occurring during drought years. Sprinkler irrigation systems, properly designed, installed and operated, have many advantages, both in terms of water quantity and quality. Uniform water application is possible on all types of soils. A properly designed system should result in no tailwater runoff and drastically reduced deep percolation losses, which would also result in more efficient fertilizer use. Drainage problems would be alleviated and existing surface water supplies would be more effectively utilized.

Apart from the water quality benefits demonstrated by Colorado State University (Walker, Skogerboe and Evans, 1977), there are many other advantages to farmers in converting to sprinklers. The labor savings are particularly noticeable in comparison with surface irrigation methods. With portable solid-set or permanent set systems, labor is negligible and the systems lend themselves to automation for all water application purposes.

Associated with the reduction of nutrient losses by reducing deep percolation, further fertilizer loss reduction can be achieved by the ability to use sprinkler systems to apply fertilizers at the time required by the plant. Water soluble fertilizers can be applied through the sprinklers with the timing and amount controlled to meet the needs of the plant. The ability to schedule fertilizer applications to plant needs (rather than to cultural operations as with surface irrigation methods) reduces the opportunity for leaching nutrients below the root zone. The amount of water applied can also be controlled to meet the needs of the crop, with light applications for seedlings and young plants. Water soluble herbicides and insecticides can also be applied through the sprinklers. As drainage problems are alleviated, salt accumulation on the soil surface is reduced. This reduces the hazard to seed germination and plant growth from the accumulated salts.

All of these advantages add up to a potential for cost savings and increased returns for the farmer operators. Generally, one of the major obstacles to adoption of sprinkler irrigation, however, is the high capital cost involved. The cost of converting from surface methods to sprinklers will vary markedly, depending on the particular system adopted and the acreage irrigated.

Trickle Irrigation--Trickle or drip irrigation is a recently developed irrigation method and would appear to have potential for orchard crops in the study area. This method of irrigation has gained attention during recent years because of the potential for increasing yields, while decreasing water requirements and labor input. The concept behind trickle irrigation is to provide the plant with the optimal soil moisture environment continuously. This is accomplished by conducting water directly to individual plants, through laterals running along each row, instead of providing water to the entire field as with flood or sprinkler irrigation. The multitude of lateral lines are supplied by manifold lines which connect to the main line, which in turn connects to the water source. A control head is provided, generally at the water source, to regulate pressure and flow and to filter suspended solids from the water. A fertilizer injection system is often incorporated into the control head.

A wetted profile, the shape of which is largely dependent on soil characteristics, develops in the plant's root zone beneath the "trickler" or "emitter." Ideally, the area between trees and between tree rows is dry and receives moisture only from incidental rainfall. Trickle irrigation saves water because only the plant's root zone is supplied with water and little water should be lost to deep percolation or evaporation under proper management. The only irrigation return flow is that due to a leaching fraction which may be necessary to prevent excessive salt buildup in the root zone. There is no surface runoff and very little nonbeneficial consumptive use of water by weeds. Water savings are affected through the ease with which the correct amount of water is accurately applied.

For irrigating widely spaced crops (e.g., trees), the cost of a correctly designed trickle irrigation system is relatively low in comparison to that for other solid set or permanent irrigation systems. In orchards, the cost of a trickle irrigation system may be lower than that for a solid-set or permanent sprinkler system having the same level of automation. In addition, where clogging is not a problem and emitter line maintenance is minimal, operation and maintenance costs of the trickle irrigation system are usually quite low. However, in plantings of row crops or vines, where the average distance between emitter lines must be less than 10 feet (3.05 m), the cost of trickle irrigation is relatively high. The cost of a trickle irrigation system for orchard crops is usually slightly more than $1,000 per acre ($2,469/ha). The cost of automating trickle irrigation systems is only $100-$200 per acre ($247-$494/ha).

Irrigation Scheduling--Irrigation scheduling consists of two primary components, namely evapotranspiration and available root zone soil moisture. Evapotranspiration is calculated by using climatic data. The other major category of required data pertains to soil characteristics. First of all, field capacity and wilting point for the particular soils in any field must be determined. More importantly, infiltration characteristics of the soils must be measured. Only by knowing how soil intake rates change with time during a single irrigation, as well as throughout the irrigation season, can meaningful predictions be made as to: a) the quantity of water that should be delivered at the farm inlet for each irrigation; and b) the effect of modifying deep percolation losses. With good climatic data and meaningful soils data, accurate predictions as to the next irrigation date and the quantity of irrigation water to be applied can be made. In order to insure that the proper quantity of water is applied, a flow measurement structure is absolutely required at the farm inlet.

The results of a demonstration project by Colorado State University indicate that irrigation scheduling programs have a limited effectiveness for controlling salinity in the Grand Valley under existing conditions. Excessive water supplied, the necessity for rehabilitating the irrigation system (particularly the laterals), and local resistance to change preclude managing the amounts of water applied during successive irrigations. To overcome these limitations, irrigation scheduling must be accompanied by flow measurement at all the major diversion points, farm inlets, and field tailwater exits. In addition, it is necessary for canal companies and irrigation districts to assume an expanded role in delivery of the water. Some problems have been encountered involving poor communication between farmer and scheduler, as well as certain deficiencies in the scheduling program dealing with evapotranspiration and soil moisture predictions. These latter problems can be easily rectified, however. Correcting these conditions will make irrigation scheduling much more effective and acceptable locally.

Water budgets from which the study results were generated resulted from incentive investigation on two local farms. The selection of the two study farms was intended to be representative of conditions valley-wide. Analysis of the budgets reveal that approximately 50 percent of the water applied to the fields came during the April and May period when less than 20 percent of the field evapotranspiration potential had been experienced. Salt pickup estimates during this early part of the season amounted to about 60 percent of the annual total for each field. Another indication of the importance of early season water management is presented in an analysis of irrigation efficiencies. As the season progressed, the soils became less permeable and the crop water use increased, causing marked improvements in irrigation efficiency. Thus, if irrigation scheduling is employed in its optimal format, salt pickup from the two fields could have been reduced as much as 50 percent or more.

The results of this demonstration project show that irrigation scheduling is a necessary but not sufficient tool for achieving improved irrigation efficiencies. The real strides in reducing the salt pickup resulting from overirrigation will come from the employment of scientific irrigation scheduling in conjunction with improved on-farm irrigation practices. This combined effect could result in reduction of 300,000 tons (330,000 metric tons) annually of salt pickup from the Grand Valley, depending upon the degree of improvement in present on-farm irrigation practices.

Water Removal Subsystem--

Drainage investigation in the Grand Valley began shortly after the turn of the century when local orchards began failing due to saline high water tables. Study showed the soils to be not only saline but also having low permeabilities. At the time, the future development of the Bureau of Reclamation's "Grand Valley Project" loomed as a severe threat to the lowlying lands between it and the Colorado River. In answer to these drainage needs, the solutions were clearly set forth but never fully implemented because of the large capital investment required. However, the citizens of Grand Valley did elect to form a drainage district supported by a mill tax levy in order to construct open ditch drains and some buried tile drains to correct trouble spots.

The construction of open drains has played an important role in Grand Valley. These drains serve as outlets for tile drainage systems, as well as intercepting and conveying tailwater runoff which would otherwise flow over surface lands, infiltrate and contribute to additional subsurface ground water flows, subsequently reaching the Colorado River with increased salt pickup.

This study was undertaken with the history of local drainage well in mind, but for a different purpose--that being the skimming of water from the top of the water table before it reaches equilibrium with the highly saline soils and aquifers below, as well as demonstrating to local farmers the benefits in increased crop production by improved drainage.

Three farms were selected for drainage investigations during the 1972 irrigation season. The studies showed that the drainage problems on two of the farms could be alleviated by improved on-farm water management. In particular, increasing irrigation efficiency during the early season would sufficiently reduce deep percolation losses, which in turn would keep the ground water level at a satisfactory depth below the ground surface to allow good crop production.

The results from the two farms illustrate the adage--"an ounce of prevention is worth a pound of cure." Thus, the first steps in a salinity control program are to minimize: a) seepage losses from canals and laterals; and b) deep percolation losses from croplands (ideally, the deep percolation losses would not exceed the leaching requirement). By minimizing the amount of moisture reaching the ground water, the requirements for field drainage will also be minimized.

The third farm had been originally selected for investigation as an example of the worst conditions encountered in Grand Valley. A 11.6 acre (4.7 hectares) field on this farm was selected for construction of a field drainage relief system. Besides having a very high ground water level, the soils have low permeability, high salt content and the topography is irregular. In order to correct these deficiencies, the following measures were taken: a) a drainage system consisting of 4-inch diameter (10.2 cm) perforated corrugated plastic pipe was installed on 40-foot (12.2 m) centers at an average depth of 6 feet (1.8 m); b) the field was leveled to allow better surface irrigation; c) the field was plowed to a depth of 2 feet (60 cm) to increase surface permeability; and d) the field was planted in salt tolerant Jose Tall Wheatgrass with a cover crop of oats.

Studies of the three farms, plus two additional farms investigated for irrigation scheduling, show that field drainage effluents had a salinity average of 3,000 mg/l less than the present subsurface irrigation return flows reaching the Colorado River.

A principal advantage of field drainage (e.g., tile or perforated pipe) is that the effluent is a point source which can then be placed into a collection system for disposal (e.g., evaporation ponds, deep well injection, or desalination). Drainage in conjunction with salt disposal would be required to achieve a zero discharge policy for irrigation return flows.

As part of this study, an alternative use of drainage was considered. During the 1950's, pump drainage from the deep cobble aquifer was tested and proved most effective for reclaiming croplands. By itself, pump drainage offers no salinity control benefits because the salinity of the pump drainage effluent is comparable to the salinity of subsurface irrigation return flows reaching the Colorado River. Pump drainage in combination with desalination would be effective in reducing salt loads returned to the river. In determining the costs of pump drainage in combination with desalting, it becomes apparent that this alternative is quite costly. However, with the recent advances in desalination technology, this alternative method of decreasing salt loads of river systems is certain to become increasingly feasible as time progresses. This control measure would likely be considered as the final step in an overall salinity control program, which would only occur at some time in the future.

Cost-Effectiveness Relationships

The cost-effectiveness relationships for the previously described on-farm management possibilities were examined in an optimization context. The results shown in Figure 15 are interesting. Total capital costs in millions of dollars were plotted against the expected reduction in annual salt load from the Valley for the minimum cost array of practices. The curve agreed with data reported recently by the Soil Conservation Service in a public information brochure.

Two major strategies evolved in the analysis of on-farm improvements: 1) improvements to the existing furrow irrigation practices creating salinity reductions of up to about 150,000 metric tons; and 2) conversions from furrow to sprinkler or trickle irrigation to provide controls of up to approximately 250,000 metric tons. Of particular interest here is the fact that both alternatives are mutually exclusive. In other words, in implementing an on-farm salinity management plan, either one or the other is optimally chosen, depending on whether the goal for salinity reduction is less than, or more than, 150,000 metric tons per year (Figure 15). For instance, if planners selected on-farm improvements to reduce salinity by more than 150,000 metric tons, the alternatives would be limited to changing to sprinkler and drip irrigation methods. Below the 150,000 metric ton figure, improvements to the existing furrow irrigation practices would be optimal. This structure of the cost-effectiveness functions is unique among the alternatives as the reader will note in succeeding sections. This uniqueness is based on the fact that on-farm improvements themselves are mutually

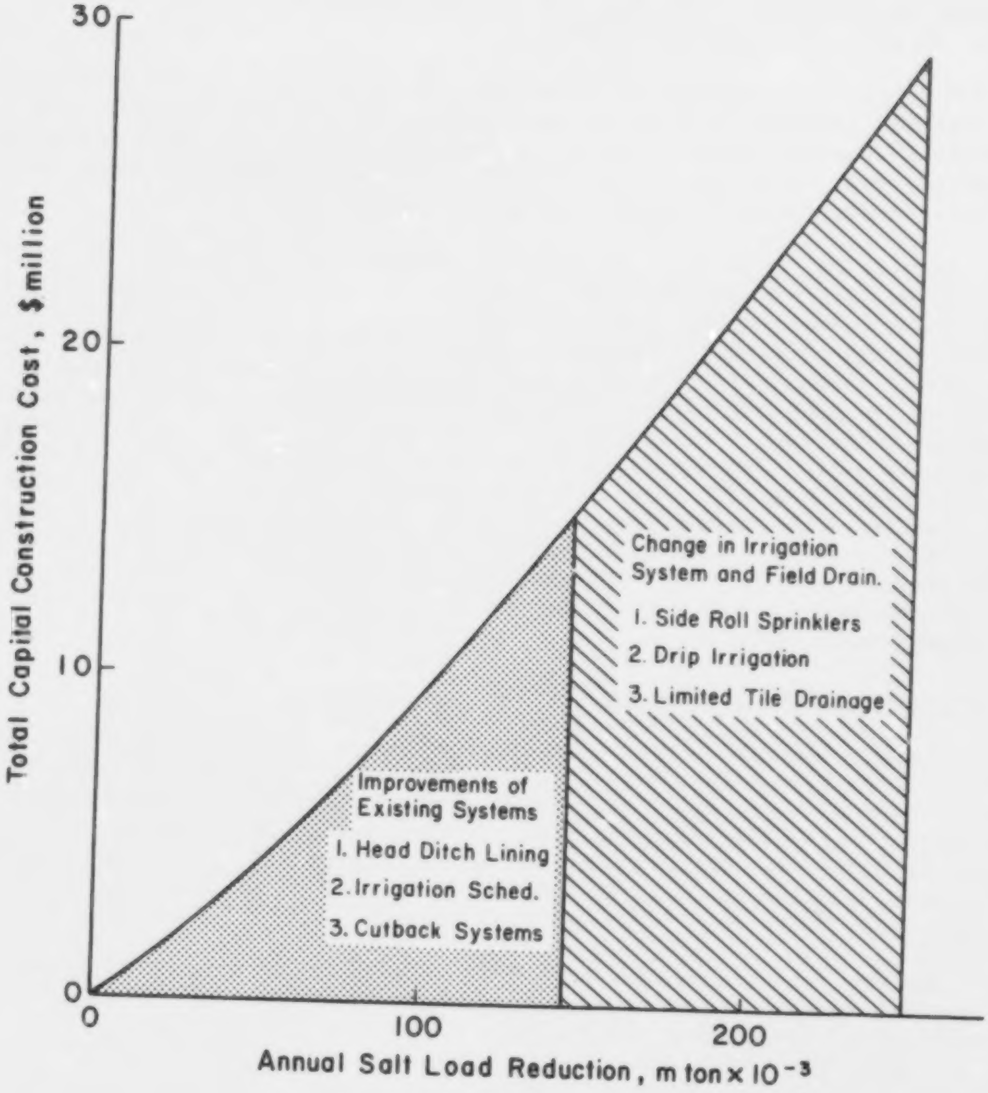


Figure 15. Optimal on-farm water management strategies in the Grand Valley (Walker, Skogerboe and Evans, 1977).

exclusive and finitely limited in their expected effectiveness. For example, head ditch linings would not be considered in the conversion to a sprinkler system.

Laterals are defined as the small capacity conveyance channels transmitting irrigation water from the supply canals and ditches to the individual fields. Most of these laterals operate in a north-south direction and can carry the flows in relatively small cross-sections. The cost of concrete lateral lining is approximately $16/m. Alternative use of PVC pipe approximates concrete lining costs for this capacity and a further distinction will not be made. However, by this assumption we are neglecting the small seepage losses which would still occur from concrete lined channels.

The Grand Valley laterals extend approximately 600,000 meters, less than one half the length of field head ditches. Seepage under existing conditions contributes about 202,000 metric tons, or slightly less than the on-farm contribution. Although no attempt was made to distribute the lateral lining costs to account for variable capacity, the cost effectiveness function for Grand Valley lateral lining is about $49.50 per metric ton. Thus, the estimated costs of lining the total lateral system in the Valley is about $10 million.

The analysis of canal and ditch linings for the Grand Valley are presented in Figure 16, in which the upper curve represents the minimal cost curve. At any point along this curve, a vertical cost distribution among the alternative canals indicated the optimal investment in each canal system.

Application of desalting technology has been analyzed. The results show that a desalting cost-effectiveness function for the Grand Valley, assuming pump drainage, reverse osmosis and deep well injection of brines, would be approximately linear at $310 per metric ton of salt removed.

The individual cost-effectiveness functions for each previously discussed alternative can be integrated to determine the best combination of technological alternatives for the Grand Valley. The results of an optimization analysis are presented in Figure 17.

Presentation of the best combination of technological alternatives deserves explanation. First, it must be realized that the four major technological alternatives (lateral lining, on-farm improvements, canal linings, and desalting) only represent what might be denoted as "structural measures." Consequently, nonstructural alternatives such as land retirement, influent and effluent controls, pollution taxes, and other nonstructural options are not included. The structural improvements would, however, include irrigation education necessary to implementation of improvements.

The second point which should be examined is the value of this sort of analysis. In Grand Valley, existing plans call for the lining of canals, ditches and laterals in combination with some on-farm improvements. Desalting is probably not being considered. Canal linings would cost approximately $40 million (in 1976 costs) and reduce salinity 110,000 metric tons. Lateral lining is estimated to cost about $30 million by the Bureau of Reclamation,

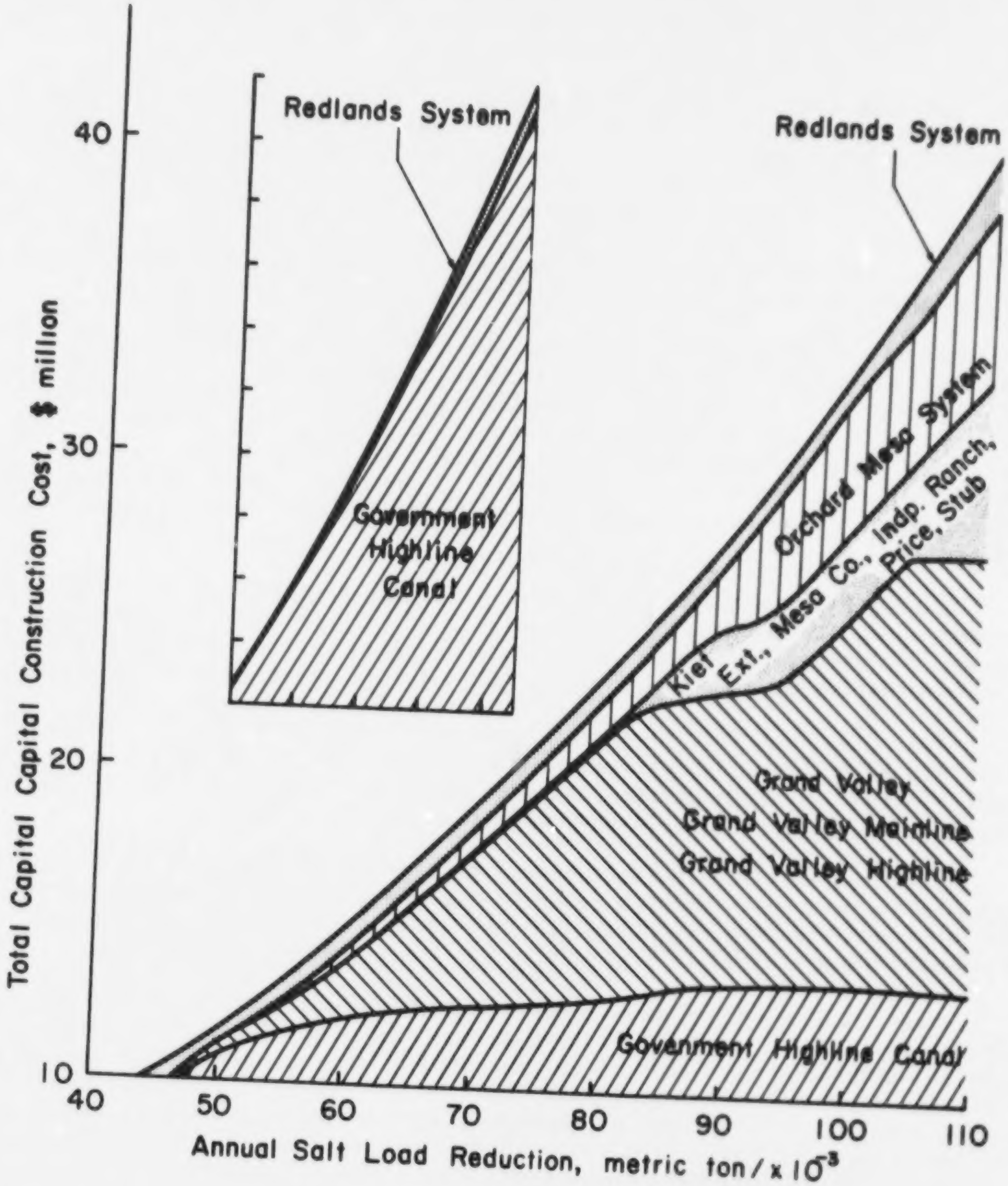


Figure 16. Minimum cost canal and ditch lining strategy for the Grand Valley (Walker, Skogerboe and Evans, 1977).

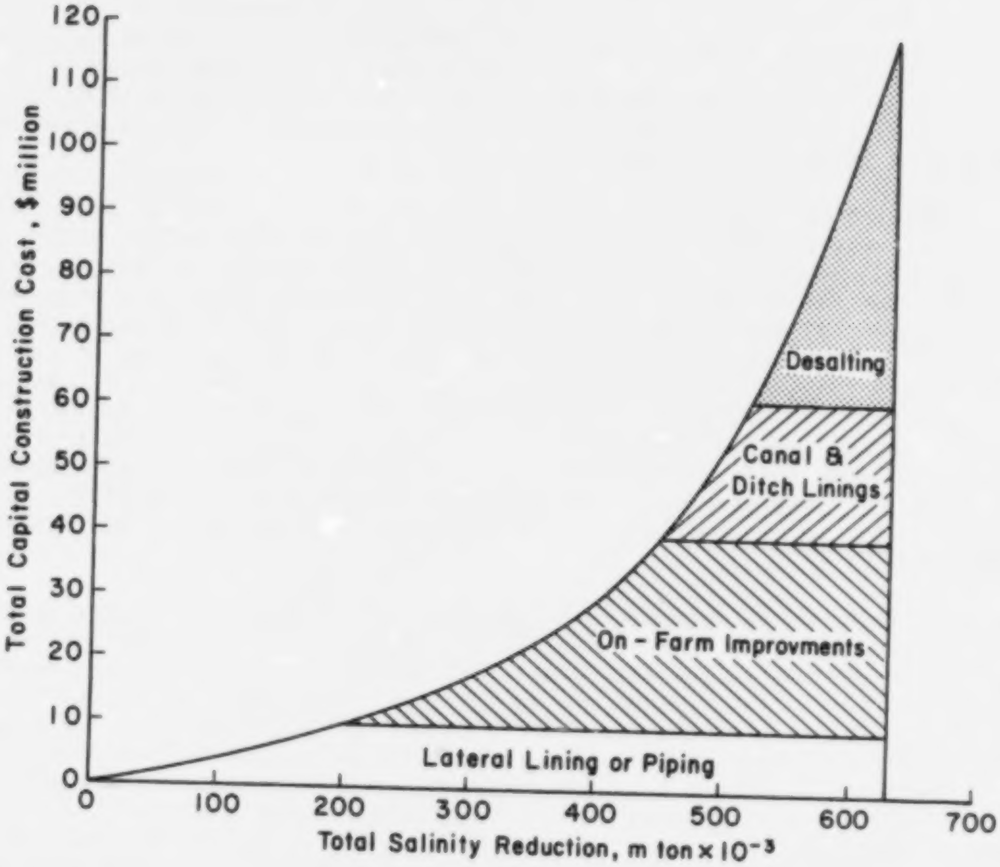


Figure 17. Minimum cost salinity control strategy for the Grand Valley (Walker, Skogerboe and Evans, 1977).

but should be possible for at least one-third this figure ($10 million) based upon field research by CSU, and would reduce salinity by about 202,000 metric tons annually. Under their most intensive plan, the Soil Conservation Service estimates that $23 million could be spent for on-farm improvements to produce a 209,000 metric ton improvement. (Figure 17 indicates that $23 million would impact on-farm salt sources by 205,000 metric tons annually.) Therefore, 73 million dollars would be invested in improving irrigation return flow quality by an equivalent 517,000 metric tons ($141.20 per metric ton). Examination of Figure 17 indicates that a salt load reduction of 517,000 metric tons could be achieved at a cost of only $57 million by using less canal lining and increasing on-farm improvements. This is a svaings of more than 25 percent, or $16 million.

A third point of interest is: "How much salinity control is feasible given current estimates of damage to downstream users?" Walker (1975) reviewed much of the literature descriptive of the California, Arizona and Republic of Mexico damages. At that time, Valantine (1974) has proposed damages of $175,000 per mg/l of increase at Hoover Dam ($146 per metric ton in Grand Valley, assuming 8 percent interest). Other estimates in terms of equivalent damages attributable to Grand Valley range upward. A representative figure is $190/metric tons as proposed by the Bureau of Reclamation (Leathers and Young, 1976). If the minimum cost curve in Figure 17 is differentiated to approximate marginal costs and is congruent with damage figures, the $146 per metric ton damage estimate of Valantine (1974) falls at a 400,000 metric tone reduction, while the $190 per metric ton occurs at 450,000 metric tons.

By not considering secondary benefits in the Grand Valley, or obviously all the consequences in the Lower Basin, the level of investment in the Grand Valley should not exceed $30-40 million. Otherwise, the costs are apparently not justified by the damages and another salt contributor (e.g., Lower Gunnison Valley) should be evaluated for possible salinity control. The conclusion is, therefore, that the best technological alternatives for the Grand Valley are the on-farm improvements and lateral linings. If downstream damages can be shown to be higher, then limited canal lining should proceed. Furthermore, irrigation improvements should consist of conversion to other methods rather than treatments of (tuning-up) the existing system. This conclusion could of course be amended if local farmers would adapt the measures necessary to achieve 85-90 percent surface irrigation efficiencies (which would imply mandatory compliance with irrigation scheduling criteria and comprehensive automation).

A final point to be made herein concerns the sensitivity of these results to the assumptions in the analysis. These estimates would need to be approximately 100 percent wrong to affect the respective feasibility of lateral linings versus on-farm improvements, and roughly the same between the remaining alternatives. Such magnitudes of error are improbable given the years of experience and the level of research effort applied to the Grand Valley by Colorado State University and many other federal and state agencies.

Evaluation of Institutional Alternatives

Land Retirement--

Much of the research effort by physical and social scientists concerned with controlling rising levels of salinity in the Colorado River Basin has focused on structural technologies. These means typically require extensive technical and material input often leading to substantial public and private investments. Land retirement is one nonstructural control option that deserves careful study since acreages reduction or desalination are the only technically feasible methods which can be employed to achieve the zero discharge objective proposed in the 1972 federal water quality legislation (P.L. 92-500).

To determine whether land retirement can be feasible on economic efficiency grounds, two sources of information are required: 1) the direct and indirect costs of removing land from irrigation; and 2) the benefits or incremental reduction in damages that would occur as a consequence. Direct costs should accurately reflect the incomes foregone from farming of the retired irrigated lands. Included in the indirect costs should be the net effects of costs and benefits issuing from resource reallocation, social transition, impacts on environment amenities, and other consequences in the affected region. Program benefits may also involve direct and indirect effects: direct benefits represent the increment of technological externality removed or penalty cost avoided, and indirect benefits (or costs) are impacts which "stem from" the direct effects. Land retirement is said to be economically feasible only if long run net benefits can be demonstrated, i.e., if incremental benefits exceed incremental costs over the life of the program (Leathers and Young, 1976).

An interindustry (input-output) model serves as the underlying structure for the analysis reported by Leathers and Young (1976). The input-output model is an analytical accounting technique commonly used in the evaluation of "total" economic impacts of exogenous (or outside-induced) change in an economy. Because of the interdependence among industries in a well-developed economy (which may include small or large regions), secondary (or indirect) impacts are often thought to be just as important as the primary (or direct) impacts of an induced change. For this reason, the basic approach adopted in the study by Leathers and Young (1976) is indirect impact analysis.

Land retirement mechanisms might include one or more of a number of options, and can be either voluntary or involuntary, depending on the level of public acceptance and participation in the program. The objective is to discontinue irrigation on selected acreage, thus eliminating all future salt loading from these sources. Specific program options evaluated by Leathers and Young (1976) involve a permanent withdrawal of water supplies.

Withholding irrigation water from previously cultivated acreage in the Grand Valley might be accomplished on a voluntary basis by state purchase of existing water rights from willing sellers (Trelease, 1960; Radosevich, 1972). Because of the Grand Valley's arid climate, this would mean that farmland is taken out of production altogether, eventually returning to desert. State purchase of privately-held water rights from legal condemnation proceedings would constitute an involuntary conversion. This would probably be necessary in the Grand Valley, for willing sellers would be hard to find.

If a voluntary land retirement program is to be viable, then a critical number of farmers in the Valley must be willing to sell their farms (or a portion of their acreage) at a price that exceeds the present value of their long-run earnings. An involuntary retirement program would surely require condemnation and the compensation would be made at the market value of representative irrigated acreage. A retirement program would have an added flexibility if willing sellers under a voluntary retirement scheme could select the marginal acreages on their farms (perhaps difficult areas to irrigate where water losses are high and productivity low) for purchase by the state--analogous to the soil bank program (P.L. 89-321). Under such an option, the costs of the program might be reduced appreciably.

Two different program options were examined by Leathers and Young (1976). One was labeled Option I and represented a partial retirement scheme. Specific areas of irrigated land which are markedly less productive (since they tend to have high salt content and/or serious natural drainage problems that hinder plant growth) were selected for retirement. Chief among the soil groups that fit this description are those silty clays and clay loams derived residually from Mancos Shale. Although these soils typically exhibit poor yields as compared with the remainder of the area, conventional irrigation practices are normally followed resulting in deep percolation and seepage losses equivalent to the area acreages. Approximately 8,600 acres (3,500 hectares) in the Grand Valley fall into this category. Together they represent 15 percent of the area's irrigated lands, and 8 percent of the area's crop output. Since these areas of relatively unproductive soils are not contiguous in large blocks, retirement of such lands would control deep percolation from fields and seepage from farm head ditches, but would not account for seepage losses in the main distribution system.

A different strategy, labeled Option II, was directed to the retiring of land in an entire irrigation district. All canals and laterals controlled as an integrated unit and the acreage (both poor and productive) they service would be withdrawn from production. With this option, land retirement would affect the canal and lateral seepage losses which would be excluded under the first option. Accordingly, the costs of retirement are compiled by Leathers and Young (1976) on the basis of two assumed rates of annual salt reduction per acre (hectare): 5.4 tons (4.9 metric tons) under Option I, and 8.2 tons (7.4 metric tons) under Option II. A sensitivity of program costs to these estimates is also reported. The Government Highline Canal, a Bureau of Reclamation project operated by the Grand Valley Water Users Association and which serves approximately 20,500 acres (8,300 hectares) of irrigated crops, was chosen to illustrate the impacts of Option II. It is assumed that this district is representative of the Valley as a whole in terms of both productivity and salt pickup, so that results could be generalized to a full retirement program (Leathers and Young, 1976).

The adverse effects of reduced crop production in the Grand Valley Trade Area are summarized in Table 10. Annual direct and indirect costs, measured in terms of reduced community income, are estimated for the retirement of

TABLE 10. COMMUNITY INCOME REDUCTION UNDER TWO OPTIONS FOR RETIRING IRRIGATED LAND IN THE GRAND VALLEY TRADE AREA
(taken from Leathers and Young, 1976)

Impacted Sectors	Total Acreage	Gross Income Per Acre[a]	Sectorial Income Multipliers[b]			Community Income Reduction in $1000[c]			
			Direct	Indirect	Total	Direct	Indirect	Total	Nonrecoverable
OPTION I: RETIREMENT OF SELECTED LOW PRODUCTIVITY LANDS									
Forage and Feed Crops	6,050	$ 158.40	.4020	.4530	.8550	$ 385	434	819	574
Food and Field Crops	2,550	223.60	.5185	.4273	.9458	296	243	539	377
Totals	8,600	($177 ave.)				681	677	1,358	951
Annual Nonrecoverable Income Loss Per Acre: $110.23									
OPTION II: RETIREMENT OF ONE COMPLETE IRRIGATION SYSTEM (AVERAGE PRODUCTIVITY)									
Forage and Feed Crops	15,720	$ 275.40	.4020	.4530	.8550	$1,740	1,961	3,701	2,591
Food and Field Crops	4,510	537.96	.5185	.4273	.9458	1,258	1,037	2,295	1,606
Totals	20,500	($349. ave.)				$3,111	3,179	6,290	4,402
Annual Nonrecoverable Income Loss Per Acre: $214.77									

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[a] Sector gross income per acre (valued at 1975 prices) reflects a weighting of individual crops according to their proportion of the total acreage included in the sector aggregation.

[b] These multipliers, net of forward linkages, measure the change in household income (returns to local capital investment, wages and profits) per dollar of change in sector output (in this case, gross revenue per acre).

[c] Colum entries are found by multiplying the product of sector acreage and weighted gross income by the appropriate multiplier. Nonrecoverable income loss is total reduced community income less a recoverability factor of 30 percent.

Options I and II under a regional accounting stance. These costs are derived from sectoral income multipliers which are net of forward linkages. In this adjusted form, the multipliers measure direct and indirect changes in household income per dollar change in output of the impacted crop sectors.

The forage and feed crops sector includes corn grain and silage, permanent pasture and alfalfa; sugar beets and small grains are handled in the food and field crop sector; and orchard and vegetable enterprises are represented in the fruit and specialty crop sector of the model. Since orchard and other high value crops are rarely grown on poorer soils, the fruit and specialty crop sector is not considered under the first option.

Assuming a recoverability of displaced resources at 30 percent, a cutback in production involving 8,600 acres (3,483 hectares) of poor quality soils in the Grand Valley would generate a net loss in community income of $951,000 annually. Under Option II, which retires 20,500 acres (8,303 hectares) of average productivity, the loss if $4,402,000. On an annual per acre (per hectare) basis, these income losses are approximately $110 and $215 ($272 and $531 per hectare), respectively.

These costs are compared with the lower bound estimates (based on a national accounting stance) in terms of total program costs (Part A) and cost-effectiveness (Part B) in Table 11. Total program costs reflect reduced income plus additional charge for implementation and administration of the program. These charges are estimated at 10 percent of annual income losses. Since the amount of salts avoided by retiring selected irrigated croplands is not known with certainty, both higher and lower estimates of the provisional salt pickup rate per acre were included in the analysis of Table 11 to demonstrate the sensitivity of this parameter to the cost-effectiveness of the program.

In general, the incremental costs of salt removal (in dollars per metric ton), using the provisional estimates of salt pickup, appear to be competitive with other more expensive controls such as canal lining, drainage and desalting. However, the cost-effectiveness of the program is quite sensitive to assumptions regarding estimates of salts removed and accounting stance. Accordingly, it is important that these assumptions are considered very carefully in comparing alternative salinity control programs. For example, the cost of partial retirement (Option I lands) vary from $6.13 per ton ($6.76/metric ton) to $14.30 per ton ($15.76/metric ton) depending on the assumed rate of salt pickup per acre, and more than double if a regional accounting stance is assumed. Leathers and Young (1976) believe that the regional accounting stance provides a fairly generous upper bound on total program costs.

Evaluation of Taxing Alternatives--

Varied reasons exist for not using taxation as a method of managing water quality, but certainly an important one in the case of agricultural pollution (such as salinity) is the difficulty in identifying sources and amounts of pollution so that the appropriate penalty can be imposed. There is also the problem of the farmers' inability to pass on this cost, so that it shows up in the price of the final agricultural product.

TABLE 11. SUMMARY OF ANNUAL REGIONAL COSTS AND COST EFFECTIVENESS: UPPER AND LOWER BOUND ESTIMATES FOR THE TWO LAND RETIREMENT OPTIONS (taken from Lethers and Young, 1976).

Measures and Options	Estimated Annual Costs (1975 Dollars)			
	Lower Bound[a]		Upper Bound[b]	
	Per Acre	Total	Per Acre	Total
A. PROGRAM COSTS[c]				
Partial Land Retirement, Option I:				
Income Reduction	39.00	335,400	110.23	951,000
Total Program Costs	42.90	368,940	121.25	1,046,100
Complete Land Retirement, Option II:				
Income Reduction	90.00	1,845,000	214.77	4,402,000
Total Program Costs	99.00	2,029,500	236.25	4,842,200

B. COST EFFECTIVENESS[d]

Salts Removed in Tons Per Acre	Dollars Per Tons	
	Lower Bound	Upper Bound
Partial Land Retirement, Option I:		
3	14.30	40.42
5.4	7.94	22.45
7	6.13	17.32
Complete Land Retirement, Option II:		
5	19.80	47.25
8.2	12.07	28.81
11	9.00	21.48

[a] Assumes a national accounting stance and perfect mobility of displaced resources; hence the costs reflect compensation payments to participating farmers as determined by income capitalization of long run earnings to irrigated farming.

[b] Assumes a regional (or local) accounting stance, 30 percent recoverability of displaced resources, and the absence of forward linkages. Costs are expressed in terms of reduced community income in response to the direct, indirect and induced effects of reduced production.

[c] Total program costs reflect additional charges for implementation and administration which are assumed at 10 percent of reduced income.

[d] Estimated annual costs per acre divided by the indicated rates of salts removed in tons per acre.

The basis for deciding upon the structure of a taxing system may be selected from a number of alternatives which can be grouped into two classifications. The first is a taxing alternative in which assessments are made against selected salinity producing processes according to an objective of least cost criteria. The second group of taxing alternatives are those restrained to applying some tax to each process. Since the proposed tax is to stimulate the structural and management improvements which would be encouraged to alter existing practices, the taxing selected salinity producing process was not considered a feasible application to salinity problems and the scope of the work by Walker (1975) was limited to the second classification.

Model Linkages--Three models were used by Walker (1975) to generate results relating to the salinity problem in the Colorado River Basin, and more specifically the Grand Valley. The hydro-salinity model delineates the agricultural activities causing salinity and quantifies their effects. An analysis of damages created through the use of saline water supplies in the Lower Basin identifies the damages originating in the Grand Valley by tracing the salinity concentrations back upstream. Thus, the linkage between these two models is the annual cost per ton of salt attributable to the study area.

The interaction of the models noted above and the input-output economy model of the Grand Valley can be established with a "pollution or salinity coefficient." The salinity coefficient linking the three models together may be defined as the dollar cost of salinity related detriments per dollar of output from each economic sector in the local economy. In the input-output model by Walker (1975), six of the principal Grand Valley crops are delineated as industries in the processing section (various crops) of the transactions table (Table 12). Since the croplands are the sources of the salinity, the salinity coefficients only have non-zero values for the crop industries. In mathematical terms:

$$\beta_i = \frac{T_{Di}}{t_i} = \frac{\gamma_i A_i C_s}{t_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

in which β_i is the salinity coefficient, T_{Di} is the total salinity detriments in dollars associated with the ith crop, t_i is the total output in dollars from the ith crop in the Valley, γ_i is an equivalent salt loading parameter for the ith crop in tons per acre, A_i is the acreage of the ith crop, C_s is the unit salinity detriment from one metric ton of salt originating in the Grand Valley in dollars per metric ton.

The equivalent salt loading parameter, γ_i, requires some explanation. The salinity resulting from the irrigation of the six crops consisted of a quantity of salts picked up from the area through leaching and a concentrating effect due to evapotranspiration. Both effects were derived as salinity concentration increases in the Valley outlet. In order to express these salinity effects in terms of tonnage, the total salt loading necessary to cause the same increase in concentration is defined as the equivalent salt loading. In this manner, the concentrating effects are also included in the analysis of salinity detriments and associated taxes.

TABLE 12. SUMMARY DATA TABLE FOR TAXING ALTERNATIVES (taken from Walker, 1975).

Coefficient	Cropland Industries in the Processing Section					
	Alfalfa	Corn	Orchards	Pasture	Small Grains	Sugar Beets
α_i	1.23	2.20	2.24	1.31	1.51	2.53
β_i	0.55	0.29	0.11	1.88	0.63	0.15
γ_i	6.70 (16.54)	8.30 (20.49)	5.60 (13.83)	7.10 (17.53)	9.90 (24.44)	9.10 (22.47)
A_i	14,600 (5,913)	14,304 (5,793)	6,936 (2,809)	10,319 (4,179)	7,404 (2,999)	5,261 (2,131)
T_{Di}	1,155,000	1,409,400	457,600	864,800	863,100	568,500
ρ_i	143.84 (355.42)	339.77 (839.56)	599.77 (1,482.01)	44.58 (110.12)	185.04 (457.23)	720.40 (1,780.08)

α_i = The business multiplier for the ith crop. It is the column sum of the table of direct and indirect coefficients derived from the transactions table for the Grand Valley. If, for example, one dollar's worth of alfalfa is produced, an additional $0.23 will be generated in the economy (harvesting, replacement parts, etc.).

β_i = A salinity coefficient equal to the ratio of salinity detriments created by the ith crop to the direct economic output from the industry in dollars/dollars.

γ_i = The equivalent salt loading per acre of crop i. Equivalent loading is the total tons of salt per acre which would produce both the salinity increases due to salt pickup and the concentrating evaporative effects (values in parenthesis are metric equivalents in metric tons per hectare).

A_i = The acreage of the ith crop (values in parentheses are hectares).

T_{Di} = The total downstream damages caused by the ith crop, in dollars per ton.

ρ_i = The gross revenue from the ith crop and equals the yield multiplied by the commidity price in dollars per acre (values in parentheses are dollars per hectare).

A summary of the most important data and coefficients generated by Walker (1975) is presented in Table 12. Other data presented for later reference include the business multipliers, α_i; per acre gross revenue, ρ_i; salinity coefficient, β_i; equivalent salt loading variable, γ_i; crop acreage, A_i; and the total salinity damages arising from the respective crops, T_{Di}.

Taxing Alternatives--The coefficients integrating the three modeling systems *discussed earlier* present some interesting alternatives for assessing taxes against the croplands in Grand Valley to affect salinity control. The formats of alternative taxing have been identified as follows:

1. Directly related salinity damages.
2. Per acre equivalent salt loading.
3. Salinity coefficients.
4. Gross revenue.

Direct Damage--The directly related salinity damages from each of the crop industries are functions of the T_{Di} values listed in Table 12. It is necessary to define a new coefficient, u_i, to represent the fraction of the salinity detriments that are to be assessed against the ith crop. Thus, for direct damages:

$$u_i = \frac{T_{Di}}{\Sigma T_{Di}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Then the distribution of taxes is computed by multiplying the respective value for u_i by the total salinity detriments to be offset. For example, if the decision is made to reduce salinity damages in the Grand Valley by an equivalent salt loading of 50,000 tons (45,360 metric tons) annually, and assuming a detriment cost of $11.83 per ton ($13.04 per metric ton), then taxes amounting to $591,500 annually need to be levied in the Valley. The values of u_i from Equation 2 for the six crop industries are 0.217, 0.265, 0.086, 0.163, 0.162, 0.107, respectively. Thus, for alfalfa, the tax would be 21.7 percent of the $591,500 and then determined on a per acre basis which comes to $8.79 per acre ($21.70 per hectare).

The parameter, u_i, represents the tax on crop i when the salinity detriments are to be reduced one dollar. Certain of the crops grown in the Grand Valley, pasture specifically, have relatively low net revenue. In fact, research in the Department of Economics at Colorado State University (Young, et al., 1975) has established that net revenues from pasture are negative at the present time. The taxes, therefore, may exceed the profits for certain of the crops. The unit acre tax levied under this method is reasonably well suited to improving water use efficiencies under each cropping system by tending to tax the least efficient irrigators at a higher rate than those irrigating crops with better water utilization.

Equivalent salt loading--The primary unit in the salinity problems of the Colorado River Basin is the ton of salt being carried by the water flows. Historically, the salinity sources considered for first priority in an implemented control program have been those with the highest salt loading characteristics. Consequently, a tax based upon relative salt impacts per unit area may be feasible. The tax distribution coefficient, u_i, in this situation is computed as follows:

$$u_i = \frac{\gamma_i}{\Sigma\gamma_i} \quad \ldots \quad (3)$$

The tax distribution coefficients for the crops are 0.143, 0.0178, 0.0121, 0.152, 0.212, and 0.194, respectively. This alternative shifts the tax burden generally to the higher value crops which also have higher salt loadings. For instance, alfalfa production taxes are reduced about 34 percent, while sugar beets are increased by approximately 81 percent. The remainder of the crop tax percentage are either reduced (corn--33 percent; pasture--17 percent) or increased (orchards--41 percent; small grains--31 percent) in order to completely distribute the salinity detriments.

Salinity coefficients--The previous two methods of taxing were based on the linkages between the hydro-salinity model and the downstream externality model. However, neither of these methods consider the local economic relationships as would a tax based upon the salinity coefficients, β_i. The salinity coefficients represent a linkage between all three models by expressing salinity detriments as a function of the economic output from the individual cropping systems. The distribution coefficient can again be defined in a manner placing the heaviest tax on the most damaging crop in terms of the salinity coefficients:

$$u_i = \frac{\beta_i}{\Sigma\beta_i} \quad \ldots \quad (4)$$

The tax distribution coefficients are radically shifted in this case from those discussed previously with more than 52 percent being assessed against the pasture acreage. Even if the salinity coefficients are adjusted by multiplying by the business multipliers, α_i, to indicate the detriments per dollar of direct and indirect economic output, the distribution remains approximately the same.

A taxing system placing a heavy burden on the pasture industry would not emphasize either of the principles noted in earlier alternatives. First, only orchards and alfalfa currently cause less per unit area salt loading and thus the potential for increasing water use efficiencies would be less. And, secondly, taxes against pasture are levied on a low income industry where the ability to pay is probably marginal. This would induce severe changes in the cropping pattern to minimize pasture acreage, thereby actually compounding the salt loading.

Gross revenue--The nature of any tax system in this country seems to emphasize higher rates for the higher income system, whether they be industries or individuals. Taxing on the basis of gross revenues per acre is an "ability to pay" concept slightly more extreme than the equivalent loading method. In this case, the distribution coefficients are defined as:

$$u_i = \frac{\beta_i}{\Sigma\beta_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

A summary of the gross revenue tax distribution coefficients along with those determined earlier are tabulated in Table 13.

TABLE 13. SUMMARY OF SALINITY TAX DISTRIBUTION PERCENTAGES FOR VARIOUS TAXING ALTERNATIVES (taken from Walker, 1975).

	Alfalfa	Corn	Orchards	Pasture	Small Grains	Sugar Beets
Direct damages	21.7	26.5	8.6	16.3	16.2	10.7
Equivalent salt load	14.3	17.8	12.1	15.2	21.2	19.4
Salinity coefficients	15.2	8.0	3.0	52.1	17.5	4.2
Gross revenue	7.1	16.7	29.5	2.2	9.1	35.4

Comparison of Taxing Alternatives--The four taxing alternatives discussed above are by no means an exhaustive list of the possibilities, although they were selected to represent the set of taxing policies aimed at stimulating improvements in local irrigation systems. The purpose of this analysis by Walker (1975) was to illustrate how the linkage of economic and hydrologic models can be made to assess the concept of pollution taxation as an instrument to effect solutions to water pollution problems.

A comparison of the taxing plans presented should center on two major questions: 1) how well will the measure induce local salinity control improvements; and 2) what would be the local economic impact of a taxing program. The overall objective inherent in the first question precluded consideration of taxing measures that did not encompass the entire irrigated system.

Approximately one-half of the salt pickup in the Grand Valley comes from seepage losses in the water conveyance system and research presented previously indicates that rehabilitation of laterals and their appurtenances is probably the initial salinity control measure to be implemented. Such a program must be undertaken in cooperation with local land owners since most of the conveyance system is privately owned and operated. However, the application of water on the croplands themselves also requires a substantial refinement. Consequently, an important comparison of the taxation procedures would be how well each procedure would encourage either self-improvement or offset the costs of having certain improvements made by governmental agencies. In this regard, each of the methods except salinity coefficients would work well. Pasture in the Grand Valley tends to be a relatively small unit operation where people support a few animals, many of which are used for recreational purposes. Although water use efficiencies are already relatively low, yields would not be significantly increased by improving efficiency. The large tax assessments against pasture lands derived from using salinity coefficients would do little to encourage local irrigation improvements on the farm itself, although rehabilitation of conveyance systems would probably result. Of the remaining three alternatives, taxation by direct damage calculations probably does not sufficiently emphasize the importance of on-farm improvements, whereas a gross revenue basis, which is highly subject to the variation in commodity prices, tends to overemphasize the on-farm salinity control measures. Thus, a system of taxing based on equivalent salt loading would probably result in the best balance of conveyance and on-farm improvements.

One of the reasons for not including total tax assessment for the Grand Valley under the entire range of possible salinity improvements is the capability of local irrigators to reduce the salinity detriments downstream at substantially less cost than the damages being caused. For example, Skogerboe and Walker (1972) illustrated that canal linings on questionable sections with relatively low seepage rates produced more benefits than were the costs. As a result, the actual level of applied taxes would require detailed cost effectiveness functions for a given level of reduction in downstream detriments. Nevertheless, an important criteria for deciding upon the distribution of the taxes would be the local economic impact. If the distribution coefficients are multiplied by the business multipliers and summed for each crop industry, the total economic effect on the Grand Valley is determined for each dollar of applied tax. Thus:

$$\text{Total impact} = \Sigma \alpha_i u_i \text{. . . . .} \quad (6)$$

The data developed previously were utilized in Equation 6 to determine the local economic effects of taxation of the croplands for salinity control purposes. For the direct damages case, each dollar of taxation would create \$1.77 in reduced economic output at the local level. Values for equivalent salt loading, salinity coefficient, and gross revenue procedures are \$1.85, \$1.48 and \$2.18, respectively. The use and choice of taxing procedures must, of course, be left to decision-makers. However, given the local economic impacts and the capability to induce local irrigation improvements, either direct damage or equivalent salt loading appears most feasible.

Application of Results--Taxation is not likely to be employed to remedy the salinity problems in the Colorado River Basin in any form except to stimulate local irrigation improvements. There is, however, at least one application of taxation that should be seriously considered. For many years the Federal Government has offered money to irrigators on a matching basis to construct a concrete lining in a conveyance channel or install drainage lines to relieve high water table conditions. Based upon the work in Grand Valley by personnel in the Agricultural Engineering Department at Colorado State

University, one of the major problems encountered thus far is getting individual irrigators interested in improving their on-farm irrigation methods and practices. In most cases, rehabilitating the conveyance channel between the supply canal and their land is given most concern. In addition, the irrigators themselves have found it difficult at times to decide how each should contribute to the cost-sharing requirements when constructing improvements. A tax levied against the crops under each lateral with payment to be made towards the cost-sharing requirements of a federally funded salinity control program would substantially alleviate these problems. Each irrigator would be taxed according to his salinity detriments rather than ownership in the lateral and thus would be motivated to emphasize the important on-farm improvements.

Permit Approach--

One of the objectives of this research project was to analyze the effects of a permit program in achieving irrigation return flow quality control. The Grand Valley case study was chosen for analysis because there is considerable field data available for this area. Thus, the analysis applies to saline subsurface irrigation return flows which is the most common water pollution problem in the Upper Colorado River Basin. The work described below includes an evaluation of the effects of tailwater runoff control, the impact of a permit program, as well as evaluating the alternative of setting "influent" standards. Earlier experience with the Grand Valley Salinity Control Demonstration Project by Colorado State University had indicated the necessary direction for a salinity control program. The discussion that follows is an attempt to document in a simplistic and not elaborate manner the necessary thrust for a salinity control program in Grand Valley.

The Federal Water Pollution Control Act of 1972 (P.L. 92-500) created a permit system for discharges from point sources under Section 402 called the National Pollutant Discharge Elimination System (NPDES). Through the permit program, point source discharges are to be identified and their discharges monitored to ensure that the effluent discharge limitations are maintained. The permit defines the obligations of the permittee in complying with effluent limitations tailored to the specific conditions of the permittee. Also, the permit sets out a compliance schedule to be followed by the permit holder.

Because irrigated agriculture was not excluded under Section 301 of P.L. 92-500, it became subject to the permit program. Between 1973 and 1975, regulations for a permit program pertaining to irrigated agriculture were issued. There was considerable backlash from irrigators and irrigation-oriented organizations regarding the inappropriateness of such a permit program. More recently, in 1976 and 1977 EPA has proposed a new General Permit Program for irrigated agriculture.

The proposed new approach provides that water pollution from most agricultural activities is considered nonpoint in nature and thus not subject to any permit requirements. However, discharges of pollutants into navigable waters through discrete conveyances, which result from the controlled application of water, are considered agricultural activity point sources.

On July 12, 1976, the EPA issued regulations which subjected agricultural activities to general rather than individual water pollution control permits. A point source is defined in the agricultural category by these regulations as any discernible, confined and discrete conveyance from which any irrigation return flow is discharged into navigable waters. Irrigation return flow is defined as "surface water, other than navigable waters, containing pollutants which result from the controlled application of water by any person to land use primarily for crops, forage growth, or nursery operations." These regulations recognized that water pollution from most agricultural activities is considered nonpoint in nature and thus not subject to any permit requirements.

The above discussion illustrates that the difficulties in implementing a permit program for irrigation return flow quality control have been more fully recognized in the last few years. Consequently, the discussion that follows under the next two headings serves mostly as an argument for the more recent action taken by EPA. This argument will be followed by a discussion of the advantages of using influent standards, which could conceivably be included as an extension of the presently proposed EPA General Permit Program.

Nature of the Salinity Problem--Salinity problems from irrigated agriculture are the result of subsurface return flows consisting primarily of: a) seepage losses from channels such as canals and laterals; and b) deep percolation losses from croplands. These sources of irrigation return flow would be considered nonpoint; however, some portions of these subsurface return flows could be intercepted by open or tile drains, which would be considered point sources.

The NPDES permit program focuses upon the control of point sources of pollution. The primary point sources of irrigation return flow are canal bypass water, tailwater runoff, and collected drainage flows. These point sources are conveyed in channels and could therefore be subjected to the provisions of a permit program.

For the Grand Valley, the question becomes whether or not the implementation of a permit program to control point sources of irrigation return flow will have a significant impact upon subsurface irrigation return flows, which are the cause of increased salt loads reaching the Colorado River. In order to provide an answer to this question, as well as illustrate the magnitude of a permit program for Grand Valley, the following argument discusses tailwater runoff and drainage return flows.

Tailwater Runoff and Drainage--The combination of heavy soils having low infiltration rates and being "water rich" has resulted in a tremendous number of tailwater runoff discharge points in Grand Valley. These discharges are frequently reused by nearby farmers, dumped into adjacent laterals or canals and conveyed to other farms, or dumped into open drains or natural washes which convey return flow to the Colorado River.

Some examples from the lateral improvement program conducted as part of the Grand Valley Salinity Control Demonstration Project will illustrate the number of tailwater runoff discharge points, and the utilization of these discharges. Before construction, for all of the nine laterals that were included in this improvement program, there were 17 points at which tailwater was received from other laterals, 21 points at which tailwater was received from other users on the lateral for internal reuse, 29 points at which tailwater runoff was discharged to other laterals or canals for reuse, and 60 points where runoff was discharged to drains or natural washes. After construction of improvements, there were still 17 points at which tailwater was received, 21 points for internal reuse, 31 points of discharge to other laterals or canals, and 58 points of discharge to drains or washes leaving a total number of discharge points unchanged as 127. These results are for an irrigated area of 275 hectares and 137 fields.

Taking into consideration the number of irrigated fields (approximately 8,500) in Grand Valley, and the size distribution of these fields, it is estimated that there are more than 15,000 individual discharge points within the irrigated area of the Grand Valley. Therefore, in order to control tailwater runoff by permitting individual farmers, an estimated 15,000 permits for an irrigated area of 29,000 hectares would be required. In contrast, if each lateral and drain were permitted, less than 800 permits would be required. The irrigation companies could assume the responsibility for becoming the permittees, but they claim no responsibility below the turnout gate which discharges water from the company canal into the individual lateral.

The Grand Junction Drainage District has constructed 35 open drains (which discharge directly to the Colorado River) throughout much of the Valley to convey irrigation wastewater. In addition, there are 9 major natural washes on the north side of the Valley which convey irrigation return flows and thunderstorm runoff to the Colorado River. No individual or organizational entity will claim responsibility for the natural washes.

In the demonstration area, field measurements have shown that approximately 18 percent of the flows in the drains and washes consist of subsurface return flows intercepted by these channels. However, the major portion of the saline return flows reaching the Colorado River are not conveyed by these drains and washes. Consequently, if it were possible to set effluent standards for tailwater discharge, or the flows in drains and washes, such standards could only be partially successful in reducing the salt load contribution from Grand Valley.

Influent Standards--The Grand Valley Salinity Control Demonstration Project used each lateral as a subsystem because this provided control at the lateral turnout gate. This turnout gate is a critical control point in the irrigation system because it represents the terminal point of responsibility for most of the irrigation companies in Grand Valley (in some cases, there is responsibility along the upper portions of the lateral).

In turn, the control point for each irrigation company is the point of diversion from either the Colorado River or Gunnison River. The responsibility for these river diversions belongs to a water commissioner who is a state employee. The amount of water discharged at each turnout gate is the responsibility of water masters or ditch riders, who are employees of the particular irrigation company.

Generally, the water users under each lateral are not formally organized. However, in many cases they have developed good relations among themselves in developing a water rotation, or each user gets the water on a continuous basis. There are also many cases in which there is friction regarding the distribution of the irrigation water supplies, which is aggravated by the lack of flow measuring devices along the lateral for equitably distributing the water supply. Also compounding this situation are the numerous unmeasured tailwater runoff discharges which are returned to the irrigation water supply, or picked up by neighboring farmers.

In the demonstration area, the lands under the Stub, Highline and Price Ditches have the water rights tied to the land at 0.5 Colorado miners inch/acre continuous flow (38.4 Colorado Miners Inches = 1.0 cfs, or Colorado Miners Inch = 0.74 l/s). The water users served by the Grand Valley Canal and Mesa County Ditch have shares (1 share = 0.4 miners inches, or 0.30 l/s) which can be traded, sold, rented, or transferred anywhere in the system.

The most common concept about water rights (or water duty) in the project area is an old rule of thumb that 1 share per acre (or 0.5 Colorado Miners Inch) is adequate for proper irrigation and almost every farmer was sure his diversions were close to that amount. There is, however, generally only crude measurements of the water diverted from the canals into the laterals and consequently very little awareness as to water quantities.

When numerous flow measurement devices were installed under the lateral improvement program, most people found that they had been receiving 2 or 3 times their water allotment. After seeing their true rights, most irrigators stated that: "...I cannot irrigate with my shares only," and immediately asked if they could get more water. In order to facilitate these requests, allow rotation flexibility and meet peak water demands, the systems were overdesigned based upon the water rights allocations. However, proper operation of the improved lateral subsystems will result in significant diversion reduction as compared with diversions prior to this construction program.

An initial influent standard goal should be the intended water duty for the irrigated lands. This can be computed based upon evapotranspiration, crop coefficients, and acceptable irrigation application efficiency standards, which in turn are related to pollution levels being created by inefficient irrigation practices. This should be measured at each farm inlet, which can then be translated back to the lateral turnout gate taking into consideration lateral seepage losses (which could be essentially ignored if the laterals were lined or converted to pipelines. An important consideration should be to use either a volumetric water duty as a standard, or a variable flow rate which is dependent upon the changing water requirements of the crops during an irrigation season.

The approach of using influent standards has the advantage of alleviating the salinity problem by improved water management practices, rather than end-of-pipe treatment, or partially reducing the salt load by using effluent standards under a permit program. The success of an influent approach is dependent upon: a) use of numerous flow measuring devices; b) adequate technical assistance for working with and advising farmers on improved irrigation practices and methods; and c) availability of funds for making the necessary structural improvements. However, the fear of loss of a water right, either by individual irrigators or the irrigation companies, will likely be the greatest constraint in implementing a valley-wide salinity control program.

Water User Associations--

A crucial element in implementation of an effective salinity control program anywhere is gaining the participation of the users. The unit of organization should be the lateral subsystem because it is a natural hydrologic unit where farmers know each other and interact often on a face-to-face basis. Also, in Grand Valley the jurisdiction of the irrigation companies does not include the laterals in most cases; so there is an organizational vacuum for most laterals. The goal should be to gain participation by all water users on each lateral. However, this may not always be possible due to human problems. While the organization could be on an ad hoc or informal basis, experience indicates that it is probably best to aim for a formal organization with rules developed by the members themselves. A formal organization with its own rules and regulations also makes it easier for the implementing agency because all parties have a knowledge of the structure and mechanisms involved. When the leadership is defined, this facilitates the work of the implementing agencies.

The water users, for example, in Grand Junction on several laterals have organized formally as a nonprofit mutual irrigation company under the state laws of Colorado. One problem the members of these associations have encountered has been lawyer fees for incorporation. This can be overcome by providing model sets of by-laws and other provisions to farmers considering such organization. In fact, alternative models can be provided farmers and they should decide the set of rules and regulations which meet their special needs for the most effective means of operation and maintenance of the lateral system. These models could be provided in a well-prepared manual or booklet and made available to interested farmers. The booklet should explain the benefits of formal organization, how to organize legally, and the types of by-laws and provisions required. It is important that such a booklet be well illustrated and in language that is readable. Often such booklets are not well prepared and contain too much legal jargon which farmers cannot understand. The goal is to design usable materials on how-to-do-it for the farmer audience.

Technical Assistance and Farmer Participation--

Following is a brief discussion of suggested means for developing an effective partnership between those individuals and organizations providing the technical assistance and their farmer clients. This includes methods to obtain farmer participation, the training of field level workers, the development of basic training materials, farmer-client recognition, and evaluation of extension activities. The underlying philosophy and assumptions of the discussion are: a) that the findings of the present research and improvement activites at Grand Junction are applicable for other irrigated regions; and b) that a successful comprehensive salinity control program requires active farmer participation.

Farmer Participation--One of the unique characteristics of improving on-farm water management is that the degree of success is highly dependent upon the degree of participation of each individual farmer, as well as their capability to cooperate collectively for the common good of all water users. The construction of on-farm physical improvements only provides an increased potential for water use efficiency, whereas the degree to which this potential is achieved is dependent upon the operation and maintenance of the physical improvements. This in turn is dependent upon the level of technical assistance provided, farmer attitudes, and the degree of credibility between those individuals providing the technical assistance and the farmers involved.

The efforts to organize the water users under each lateral is an opportune time to develop rapport with the farmers. Credibility between farmers and technical personnel can be developed at the time of planning and implementing individual farm plans for improved water management. Credibility and good communication must exist during the collective negotiations in determining the physical improvements to be made along the lateral. Farmer participation is crucial during these stages in order to evolve a plan of development which is acceptable to the water users and satisfies the goals of the salinity control program.

The final step in this process dictates the real success of the entire program. After spending vast sums of money to construct physical improvements, the test of effectiveness revolves largely around the operation, management and maintenance of these improvements. This is the phase of the work where the rapport developed with the farmers pays huge dividends. Unfortunately, this step is very time-consuming and most frequently neglected. Considerable evaluation is required to "tune-up" these new improvements so that they are operating at their potential, and the key variable in this operation is the farmer decision-maker.

Training of Field Personnel--The primary agency providing technical assistance to farmers for a salinity control program will likely be the Soil Conservation Service (SCS). The SCS will likely cooperate with the U.S. Bureau of Reclamation (USBR) in the provision of required technical assistance. Given the levels of manpower needed to work with farmers and the current shortage of trained manpower with on-farm water management experience, special short courses for training personnel will likely be required. As a complement to technical competence, personnel working directly with farmers would know how to develop good working relationships with farmer clients and have definite skills and knowledge related to organizing farmers into water user associations for action programs. Personnel also must have the capabilities required for assisting farmers in "tuning-up" furrow irrigation practices and the maintenance of improved conveyance systems. Also, technical assistance to farmers will include convincing them to use "scientific" irrigation scheduling procedures and other improved irrigation practices. The focus on improved irrigation scheduling is essential because the piecemeal methods of scheduling in Grand Valley have been found to be inadequate for accomplishing salinity control.

Basic Farmer Training Materials--Materials are needed to motivate farmers and help them understand the importance to themselves and their communities of improving present water management practices for increased crop production and the control of salinity. Data obtained in problem identification and alternative solutions to the problem should be utilized in preparing well-illustrated materials for farmers. These materials should graphically and clearly define the problem, explain its consequences, document the contributing factors, and explain the costs and benefits. Alternative solutions should be carefully delineated and estimated costs presented.

Techniques for such communications could include slide shows, an easy-to-read booklet and selected use of local mass media channels. The slide show developed for the Grand Valley project by Colorado State University has been well received and has been presented many times in the community at specific public meetings and for civic groups. Also, selected use of local mass media has been found to be useful. Since a comprehensive salinity control program requires changes in attitudes and behavior wherever such programs are proposed, the first major consideration should be the design of definite communication strategies. To make the program successful in reaching all water users and the community, several complementary communication methods should be used over time to reinforce the central messages. Local conditions and communication sources and channels need to be identified and used with imagination. Essentially, salinity control is a problem of conservation which requires much education on the part of farmers and communities.

Farmer Client Recognition--The Irrigation Field Days held at Grand Valley on August 6-7, 1976, and other experiences have demonstrated the importance of farmer recognition. Farmers usually can sell a program to other farmers more successfully than public officials. Where possible, farmers should be given special recognition, because the success of any salinity control program rests finally with the degree of participation of the farmers themselves. There are a number of methods which can be effectively utilized for using farmer recognition to motivate other farmers.

The proper use of radio and television announcements and newspaper articles can be of considerable help in fostering enthusiasm for the program. The local newspaper provides excellent coverage on news related to natural resources and agriculture. The local newspaper in Grand Valley has been very helpful and always willing to include news articles pertaining to the Grand Valley Salinity Control Demonstration Project. The television station and some radio stations in Grand Junction have cooperated in disseminating news related to the salinity control research activities.

The news media, in addition to news reports about current activities of the salinity program, are also very interested in covering human interest stories. If these human interest reports and farmers' testimonials are well-prepared, they can create much interest with other farmers for the program. Such publicity is free and probably can generate better image-building for state and federal agencies than they can do themselves.

Awards should be given to those farmers who have made exceptional progress in improving their on-farm water management practices. Also, awards for providing leadership in the water user association under each lateral should be considered. Awards presented to each water user served by the lateral demonstrating the most efficient use of water would be highly effective in promoting the goals of an improvement program. News media coverage of such awards also provides additional incentives for improved water management on the part of other farmers. Framed photographs of farmers engaged in improvement activities with an inscription should be considered for presentation. Also, plaques could be presented to cooperators to show appreciation for their contributions.

An excellent method of involving farmers for promoting wide interest in a project once substantial progress has been made in an improvement program is to hold a "Field Day." In the Grand Valley, a Field Day could be held annually which would involve strong participation by local farmers. Water users, including irrigation company leadership, from other valleys in the Upper Basin, could be given special invitations to attend the Field Days in order to observe first-hand the implementation of a salinity control program. In addition, special tours could be arranged during other times of the year for a group of irrigators from any particular valley to visit the Grand Valley and meet with farmers who have participated in the program. The emphasis should be farmer-to-farmer interaction, with the Grand Valley farmers being highlighted rather than technical assistance personnel. These personnel, however, should play a strong backstage role in facilitating this interaction.

Evaluation of Extension Activities--It is not suffucient to randomly develop extension and promotional activities for the transfer of technologies for salinity control improvement programs. Technical personnel in such projects should be given short courses in skills needed for working effectively with farmers. Extension communication strategies should be designed into the project work plans in order that various techniques can be effectively evaluated. While technical expertise for such programs is usually adequate, there is a general weakness in designing and evaluating extension communication strategies. As stated previously, the key variable in achieving successful program implementation and long-term effective maintenance of improved systems is the farmer client himself. Since this is the case, professional assistance is required from extension or communication personnel to assure that sufficient attention is given to these important areas.

Communication techniques used for working with farmers as individuals and groups should be designed into the programs and evaluated to the same degree as the technical components and activities. Evaluative research techniques are available which, if properly utilized, can be used to determine the strengths and weaknesses of project implementation. Information from such evaluative studies is needed by sponsoring agencies and by project implementors to discover the most effective and efficient methods of working with farmers.

Water Rights and a Water Market--

The concept that is at the heart of the appropriation doctrine and which would make the most substantial impact in solving the legal and institutional constraints for alleviating water quality degradation from irrigated agriculture is the concept of beneficial use. This is a very nebulous concept which defines the measure and the limit of a water right. In general, beneficial use means the reasonableness of the diversion according to the use to which the water is to be applied. At present, what is a beneficial use for acquiring a water right may depend on whether that particular use is one recognized by the state constitution or statutes. The concept must be conceived and directed not only to types of uses but to the nature of the use on the farm with respect to the users' needs. More importantly, this concept must be viewed with respect to the users' responsibility to other downstream users and the public interest.

The concept could be used to implement water management technology. Irrigation scheduling and careful water control could be encouraged through an interpretation of the concept as prescribing to the most advanced technologically feasible management program with respect to on-farm use. Conventional methods of water application using ditches and borders and in some cases sprinkler systems have the advantage of being economically inexpensive but conversely place a great strain on the water budget due to losses through deep percolation. Where feasible, subsurface application or the trickle method could be encouraged which would have the effect of reducing the quantity of water applied and salt laden return flows.

A major change in the nature of a water right that would serve to protect the interests of the right holder and subsequent water users would be to add the element of water quality. In so doing, the right holder would have the same assurance and likewise liability in the use of diverted water within the priority system for quality purposes as he now has for quantity flows. This change would be instrumental in encouraging practices to treat or dispose of highly saline waste waters and encourage the proper application of water on the farm.

A final doctrinal impediment in the exercise of water rights is the transfer restriction of rights within an irrigation system to other uses, or outside of the basin. This constraint may exist in the substantive water law or as a result of the organizational and administrative system of the state. There are few states that prevent the sale and transfer of water rights from within or without the present uses. States restricting transfers rely upon the appurtenancy concept to prevent such shifts. However, the law should be modified or changed to reflect state encouragement in the renting, leasing, transferring or selling of water rights to other uses and places so long as the vested rights of others are protected. Although there are no restrictions on the transfer of water rights in Colorado, the organizational red tape--delay and expense--acts as an impediment. Changes in the administrative and judicial system should be made to facilitate exchange of water rights. Recognition of such a right and a change in the concept of beneficial use to include recreation, aesthetics, fish and wildlife, and other beneficial uses would serve to nullify the fear of losing that portion of the water right not exercised by permitting the transfer of the unneeded portions to other uses within the system.

Removing these rigidities in the law to give the right holder greater freedom and flexibility will eliminate many of the irrigation problems perpetuated by the appropriation doctrine. Agricultural users are subject to constraints that other users are not, which is frequently passed over when comparing the use of water for agriculture to other uses.

A substantive change in the water laws affecting the administrative organization of the state should be enacted to enable a greater degree of cooperation between the state agencies and water users. At the same time, the state should be permitted to concentrate on the development of a desirable state water plan. This change would be to enact legislation permitting the state water resources agency or other public organizations the right to acquire water through appropriation, purchase, abandonment, or condemnation. The significance can be seen at the state and interstate level by granting the state greater freedom in carrying out its responsibilities and negotiating agreements with its basin users and states.

What is needed is a means of allocating and reallocating water within the irrigation system by an organization cognizant of the needs of water users within the system, the state water development plan, and the basin and international compacts. Suggested is the development of a centralized state brokerage system to operate as a market center for the exchange and sale of water rights or renting of water available under the rights held (Radosevich, 1972). This brokerage system could be organized as a public or private institution. It would permit water users to divert only that amount of water necessary for their operation without fear of losing the unused decreed quantity and lease or rent the difference to other users. Hence, there would be an economic incentive to implement the most efficient water management practices in their operation in an attempt to reduce the necessary quantity of water applied.

A brokerage system created as a public entity could be established in the Office of the State Engineer or water planning and resource department of the state. This office or subdivision in the various basins within the state would list all available water for rent, lease, exchange, or sale. The location of available waters will determine the impact upon other vested rights, but the responsibility for delivery and protection of such other rights would rest upon either the water right holder or water acquirer. Uniform prices of units of water could be established or the available water could be sold to the highest bidder. The adoption of such a system in state organization would require changes in agency laws to permit this type of activity. Likewise, it would be imperative that the state should have the power to purchase, condemn or receive water rights in the name of the state. This would allow the state to take action against appropriators who refuse to implement efficient practices, acquire their unused rights and retain them for future use while renting or leasing the water during the interim. A percentage of the sales proceeds would be retained for the operation and maintenance expenses of the brokerage system.

FIELD ASSESSMENT OF POTENTIAL SOLUTIONS

Similar to the Yakima Valley and Middle Rio Grande case studies, the research project team interviewed various individuals who are involved with the Grand Valley salinity problem. Federal and state agency personnel located in Denver and the Grand Junction area were interviewed. Board members of irrigation districts, managers of irrigation districts and individual farmers were also interviewed.

The "Summary of Technological and Institutional Alternatives for Salinity Control in Grand Valley," shown in Table 14, was used as a discussion outline in contacts with persons being interviewed. This summary of alternatives was used in order to provide a similar approach in discussions with each individual or group of individuals. This approach was used to reduce bias and to provide information in a manner that would allow comparison of different responses to the same solution, as well as comparing responses to alternative solutions.

There were many diverse opinions expressed. Even in the same organization, there were many contradictory opinions. As would be expected, much of the diversity of opinion reflects the past experience and role of the interviewee. In fact, such tremendous differences in opinion reflect the difficulties inherent in implementing a salinity control program in Grand Valley.

Some state agency personnel were quite positive in their approach. First of all, they stated that they were awaiting the results of CSU's work in Grand Valley to define the salinity control program. They felt that a "management" approach was necessary in order to solve the problem and gain acceptance by the farmers. They were very cognizant of the water rights difficulties. They expressed some hope that setting standards and criteria for beneficial use might be possible in future years, but they were very fearful of this approach at the present time.

A very different set of responses was obtained from a small group of state agency personnel who work in western Colorado. They made such statements as, "we don't believe there is a salinity problem," "water quality in the area is improving," and "why should $100 million be spent in Grand Valley for salinity control." They were also highly concerned that any modification of irrigation return flows would be tampering with water rights. The group expressed the opinion that the present water system is satisfactory, that water in Colorado is part of the "free enterprise" system, and that all users have access to the water courts. However, they did admit that no one really knows who are all of the water right owners. There was also a strong concern expressed regarding the capability of the Soil Conservation Service to handle so many programs, the future of the 208 planning program and that decisions at "the top" will adversely affect the farmers on "the bottom." Lastly, they did not think a water market would be viable. Such opinions at least demonstrate where efforts should be made to more adequately inform people regarding the Grand Valley Salinity Control program.

In discussions with federal agency personnel, they were quite aware of the many problems that would have to be faced in implementing a salinity control program in Grand Valley. They were particularly concerned with the water rights issues because they are aware that the irrigators are "fanatically" jealous of their rights.

TABLE 14. SUMMARY OF TECHNOLOGICAL AND INSTITUTIONAL ALTERNATIVES FOR SALINITY CONTROL IN GRAND VALLEY.

TECHNOLOGICAL ALTERNATIVES

Item	Probable Effect
1. Delivery system improvements--	Prevention of seepage and operational spills.
a. Lining of canals and laterals	Reduction of subsurface flows.
b. Installation of flow measuring devices.	Control of applications, improvement of irrigation efficiencies.
2. Improved water application practices	Reduction of deep percolation losses.
a. Implementation of irrigation scheduling program.	Increase efficiency of water use via "timed" application of water.
b. Introduction of trickle and sprinkle irrigation systems.	Gain control of rates of application of water on some crops.
3. Improved management of fertilizers on crops.	Reduce costs of fertilizer and reduce concentrations of fertilizer in return flows.
4. Improved water removal subsystem by means of tile drains and treatment of effluent.	Remove water moving below root zones to prevent deep percolation, and treat this water before discharge to receiving streams.

INSTITUTIONAL ALTERNATIVES

Item	Probable Effect
1. Reallocation of water via adjudication of rights.	Reduction of "water duty" from as high as nine acre-feet per acre to 5 acre-feet per acre (or whatever amount is necessary to irrigation in the Valley).
2. Imposition of volumetric controls, on the basis of crop needs.	Promotion of efficiency in use of water, with no change in "water duty" (the right to a specific quantity of water).
3. Reduction of "water duty" by institution of abandonment procedures against users where there is waste.	Promotion of efficiency in use of water, because of change in the water right.
4. Open marketing of water rights within the river basin.	Redistribution of rights and reallocation of water based on values of water in various uses (constrained only by limits on diversion which protect rights of other users).
5. Sales by Grand Valley Canal Assn. or the Conservancy district of "surplus" water, i.e., that water which is not consumptively used).	Reallocation of water from owners of "surplus" to others who need water (constrained by capability of districts to deliver "surplus" to buyers).
6. Return flow discharge permits (quotas)	Control of effluent discharged.
a. Issued on the basis of the water rights held.	Establishes limits for discharge of pollutants by present owners and users of water.
b. Sold in an open market, with number of permits reflecting the allowable discharge of effluents.	Requires water users to pay costs of pollution. Permits tied to water use. Required designation of stream standards. Likely to result in improved use of water, shifts in use to higher value uses, some transfers of rights.
7. Effluent charges, based on costs of treatment of return flows.	Requires water users to pay costs of pollution. Makes sampling and testing of return flows necessary. Requires designation of stream standards. Likely to cause more efficient use of water. May cause shifts in use of water to higher value uses.
8. Subsidization of useful programs and practices.	Encourages adoption of technology and improvement in management of land/water resources.
a. Cost-sharing programs aimed at capital improvements.	Provides incentive for investment in distribution and irrigation systems.
b. Incentive payments for improved practices.	Encourages improvement in management of land and water for pollution control.
c. Tax "breaks" for capit	
c. Tax "breaks" for capital investments.	Same as 8(a) above.
9. Payments, i.e., rewards, for reduction of return flows or of salt/silt loads.	Encouraged adoption of measures appropriate to pollution control.
10. Technical assistance in salinity control programs.	Encourages improved management of land and water.
a. Education efforts, e.g., extension program.	Improved understanding of pollution problems, identifies alternative solutions, encourages individual actions to alleviate problems.
b. Technical assistance, e.g., Soil Conservation Service.	Facilitates adoption of improved practices, assists with improvements in distribution and irrigation systems.
11. Management of water in a project area by a voluntary non-profit organization.	Improved allocation and use of water by a management entity.

The Soil Conservation Service conducted a survey during the summer of 1975 which involved approximately 1,400 contacts. They stated that 90 percent of these contacts were favorably disposed towards a salinity control program. There has been a growing awareness and interest in recent years regarding the salinity problem in the Valley, with a correspondingly increasing willingness on the part of the farmers to cooperate with efforts to reduce the salt load reaching the Colorado River.

In discussions regarding the feasibility of implementing a water market in the area, there was some concern that this would result in new lands coming under irrigation, which would aggravate the salinity problem. The general feeling was that the physical improvements should first be completed and then the concept of a water market could be discussed.

In discussions with local people, primarily irrigation company leaders, there is a strong emphasis upon the farmer being allowed to control his own operations, rather than having government controls. The primary culprits are depicted as the part-time or weekend farmers, who allow the water to run for long periods over their fields. The suggestion was frequently made that these farmers should be made aware of the necessity to improve their water management practices.

Considerable concern was expressed locally regarding the impact of transmountain diversions by the City of Denver (and other East Slope agricultural and municipal interests) upon the quality of water received by Grand Valley. The question was also raised as to why Grand Valley should have to solve the problems of Arizona and California.

There was a strong emphasis by some local leaders that efforts should be undertaken to facilitate the organization of water users under each lateral. They felt that lawyer fees were excessive and that more expedient means should be considered for organizing the irrigators under each lateral.

The local people have a fairly good awareness of the proposed salinity control program. They are generally in favor of canal and lateral lining, as well as improved on-farm irrigation methods.

Most local people are not convinced that there will be excess water following the proposed capital expenditures for salinity control. They prefer to take a "wait and see" attitude before making any commitments regarding excess water. Therefore, their attitudes towards a water market are generally along these same lines. However, some local leaders are in favor of having the option to rent or lease excess water to water users upstream from the Grand Valley, but they do not want to make any commitments at this time.

Most agriculturalists are concerned with the increasing suburbanization surrounding the city of Grand Junction. Many of these suburbs are canal water supplied to irrigate their lawns. In many cases, suburban irrigation demands have compounded water management problems.

SUMMARY OF RESULTS

The participants in the assessment/evaluation process quite logically responded to the alternative solutions based upon their past experiences and present roles. They tended to view the problem and the proposed solutions in terms of the existing institutional framework, the costs and benefits associated with change, the impacts on established practices and methods, and the probable effects on social relationships. Knowing how people looked at the return flow problem and how they responded to alternative technological and institutional alternatives allows us now to recommend solutions, singly and in combination, that will be implementable. The Grand Valley case study has benefited from the extensive research and demonstration efforts over the past eight years. The extent of the impact of proposed technological alternatives on the salinity problem is fairly well determined. Now, we do have some good indications of what people do not like, what they think will work, what they will cooperate with, etc. This assessment/evaluation process has provided valuable insight as to the requirements for implementing appropriate technologies that will reduce the salt load contribution from Grand Valley into the Colorado River.

Evaluation of Assessment Procedure

The assessment procedure was initially tested in the Grand Valley, but it suffered from insufficient participation within all groups. The federal agency personnel were quite informed regarding the problems that would have to be faced in implementing a salinity control program in Grand Valley. Also, state agency leaders were very knowledgeable regarding the implications of salinity control. However, state agency personnel at the local level reflected many local opinions and were more opposed to change than many of the local irrigation leaders. Irrigation district managers were more flexible in their attitudes toward change, but they were constrained by their responsibilities for management of diversion and distribution facilities. They also reflected farmer-member interests, perhaps being more jealous of rights, customs, practices, and methods than farmers themselves. Managers were quite conscious of water quality problems and willing to do something about them. The sample of farmers interviewed was undoubtedly biased in favor of "better" farmers who served as local leaders of irrigation companies and the drainage district. They were generally in favor of a salinity control program provided it did not interfere with their water rights. A larger sample would have included some farmers not so well informed and not so capable of good judgment.

Evolution of Solution Packages

There was a universal negative reaction by federal, state and local personnel to controlling salinity by using a permit program. Local people, in particular, are very antagonistic and hostile towards any such efforts to control their use of water.

The preferred solutions quite obviously include those that are directed to improvement in the management of water in irrigated agriculture. They are technological--the lining of canals and laterals, the measurement of water deliveries, and the improvement of water application methods (or 100 percent federal funding), technical assistance for improved water management, and facilitating the organization of water users under each lateral. Most local people prefer to consider any possibilities of a water market, such as selling or renting excess water to water users upstream from Grand Valley, after they have seen the effects of constructing physical improvements.

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APPENDIX A

SOCIAL CHARACTERISTICS OF THE GRAND VALLEY

TABLE A-1: GENERAL SOCIAL CHARACTERISTICS

County	Median Years of School		Unemployed (%)		Occupation: Farmers & Farm Managers (%)	Median Income	Per Capita Income
	M	F	M	F			
Mesa	12.2	12.3	5.8	4.8	3.6	$8,065	$2,658

TABLE A-2: RURAL NON-FARM

County	Median Years of School	Industry of Employed: Agriculture, Forestry, & Fisheries (%)	Occupation: Farmers & Farm Managers (%)		Median Income	Per Capita Income
			M	F		
Mesa	12.2	7.9	4.3	0.3	$8,186	$2,580

TABLE A-3: RURAL FARM (1970 U.S. Census)

County	Median Years of School	Industry of Employed: Agriculture, Forestry, & Fisheries (%)	Occupation: Farmers & Farm Managers (%)		Median Income	Per Capita Income
			M	F		
Mesa	12.3	39.6	38.7	3.3	$7,226	$2,355

TABLE A-4: 1970 and 1960 POPULATION FOR GRAND VALLEY (1970 U.S. Census)

County	Total	1970						1960		
		URBAN			RURAL					
		Total	% Urban	Other Urban	Total	Places 1000-2000	Other Rural	Total	Urban	Rural
Mesa	54,374	25,994	47.8	25,994	28,380	1,822	26,558	50,715	23,650	27,065

TABLE A-5: URBAN CONCENTRATION: GRAND VALLEY (1970 U.S. Census of Population)

City	Population 1970	Population 1960	% Change
Grand Junction	20,170	18,694	7.9
Orchard Mesa	5,824	4,956	17.5
Fruita	1,822	1,830	-0.4
Palisade	874	860	1.6

TABLE A-6: PERCENTAGE CHANGE IN POPULATION: GRAND VALLEY, 1960-1970 (Source: 1970 U.S. Census of Population).

County	Total	Urban	Rural
Mesa	7.2	9.9	4.9
Colorado	25.8	34.1	2.8

TABLE A-7: Summary Rural Characteristics: Grand Valley (Source: 1970 Census of Population).

County	% Rural Non-Farm 1970	% Rural Non-Farm 1960	% Rural Farm 1970	% Rural Farm 1960
Mesa	40.5	39.9	11.7	13.4

TABLE A-8: Class 1-5 FARMS TYPE OF FARM ORGANIZATION: GRAND VALLEY (Source: 1969 Census of Agriculture).

Type of Ownership	Mesa County	
Individual or Family Farm:		
Farms	634	
(Acreage) (hectares)	(222,879)	(90,266)
Partnership:		
Farms	88	
(Acreage) (hectares)	(181,923)	(73,679)
Corporate < 10:		
Farms	17	
(Acreage) (hectares)	(78,381)	(31,744)
Corporate > 10:		
Farms	2	
(Acreage) (hectares)	(6,543)	(2,650)
Other:		
Farms	3	
(Acreage) (hectares)	(357)	(145)

TABLE A-9: TENURE OF OPERATORS: GRAND VALLEY (Source: 1969 Census of Agriculture).

Class 1-5 Farms:		
Full Owners:		
Farms	518	
(Acreage) (hectares)	(233,691)	(94,645)
Part Owners:		
Farms	193	
(Acreage) (hectares)	(226,393)	(91,689)
Tenants:		
Farms	33	
(Acreage) (hectares)	(39,999)	(16,200)

TABLE A-10: FARMS WITH IRRIGATED LAND: GRAND VALLEY (Source: 1969 Census of Agriculture).

Farms With Acres / County	1-9	10-49	50-69	70-99	100-139	140-179	180-219	220-259	260-499	500-999	1000-1999	2000 +
Mesa	139	482	92	78	73	61	51	19	59	52	19	37
a	(622)	(889)	(3,633)	(4,395)	(6.123)	(6,254)	(5,981)	(2,624)	(11,042)	(11,358)	(4,677)	(20,831)
ha	(252)	(360)	(1,471)	(1,780)	(2,480)	(2,533)	(2,422)	(1,063)	(4,472)	(4,600)	(1,894)	(8,437)

County	1969	1964
Mesa	1,162 (86,387)	1,610 (108,135)

Key: Farms
(Acreage)

TABLE A-11: PRODUCTIVITY OF FARMS: GRAND VALLEY (Source: 1969 Census of Agriculture).

	FARM INCOME															
Mesa County	$1-2,499	$2,500-4,999	$5,000-7,499	$7,500-9,999	$10,000-14,999	$15,000-19,999	$20,000-29,999	$30,000-39,999	$40,000-59,999	$60,000-79,999	$80,000 +	Class 6	Part-Time	Part Retirement	Abnormal	Total
Farms	34	177	123	70	78	59	70	54	26	17	36	68	415	92	4	

APPENDIX B

GRAND VALLEY LAND CLASSIFICATIONS

Class 1:	$40,000 or more of farm product sales.
Class 1A:	$100,000 or more of farm product sales.
Class 1B:	$40,000 to $99,999 of farm product sales.
Class 2:	$20,000 to $39,999 of farm product sales.
Class 3:	$10,000 to $19,999 of farm product sales.
Class 4:	$5,000 to $9,999 of farm product sales.
Class 5:	$2,500 to $4,999 of farm product sales or having a value of products sold of less than $2,500 provided they had the acreage or livestock operations which normally would have had sales in excess of $2,500. These would include new farm operations, farms having crop failure, and farms with large inventories and small 1969 sales. For a count of these farms, see County Table 13 or State Table 22.
Class 6:	$50 to $2,499 of farm product sales and a farm operator who is under 65 years of age and did not work off the farm 100 days or more in the census year.
Part-Time:	$50 to $2,499 of farm product sales and a farm operator who is under 65 years of age and worked off the farm 100 days or more in the census year.
Part Retirement:	$50 to $2,499 of farm product sales and a farm operator who is 65 years old or over.
Abnormal:	Includes institutional farms, experimental and research farms, and Indian reservations. Institutional farms include those operated by hospitals, penitentiaries, schools, grazing associations, government agencies, etc.